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ABSTRACT

This module discusses the hydrologic considerations that apply to land application of wastes. These are precipitation, infiltration and percolation, evapotranspiration, runoff, and groundwater. Climatic considerations that relate to wastewater storage are also discussed. Particular emphasis is given to wastewater flow, precipitation, evaporation, and seepage. The determination of the wastewater storage period by analyzing climatic factors such as location of the site, temperature, precipitation, snow cover and soil moisture is discussed. Computer programs that can be used to do this are given. (BB)

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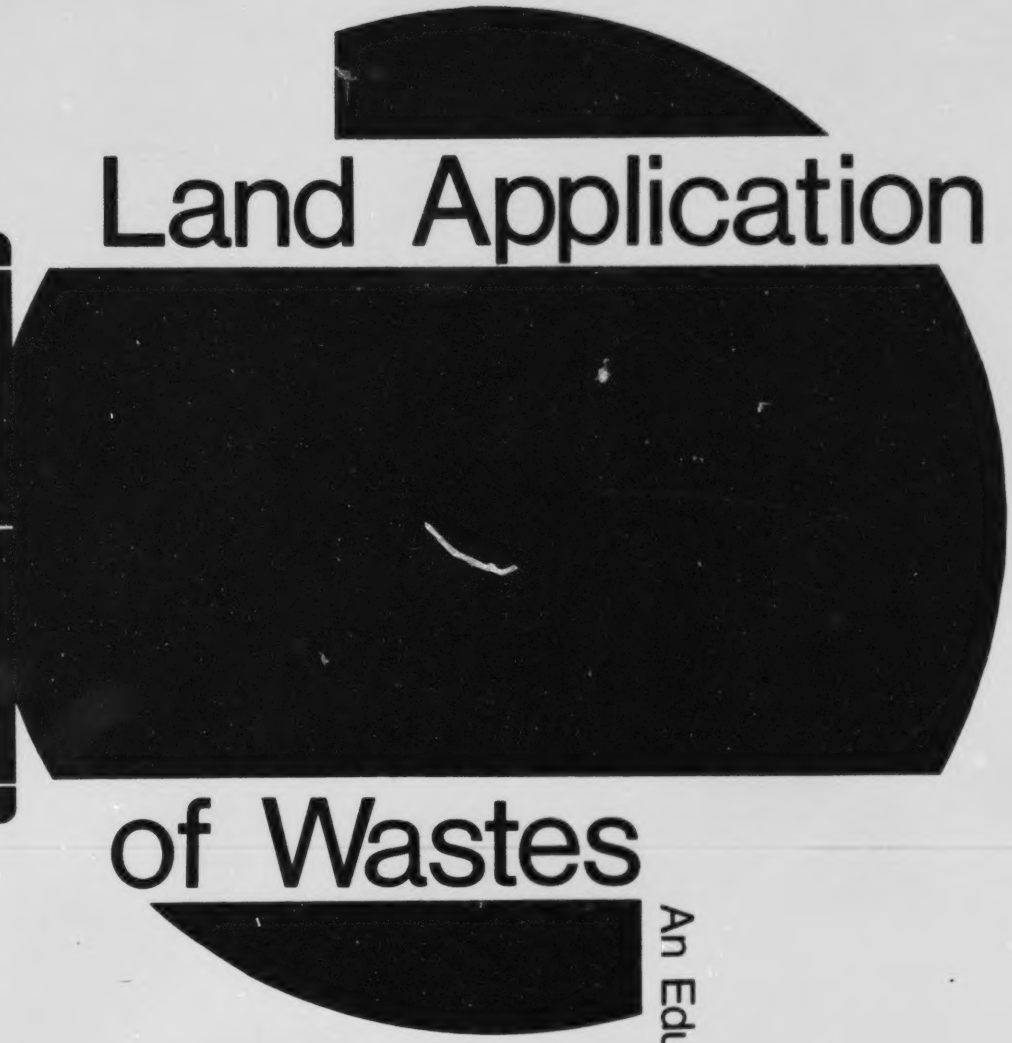
Land Application



# of Wastes

An Educational Program

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CLIMATE AND WASTEWATER
STORAGE

Module 8

January, 1978

SE 025 022

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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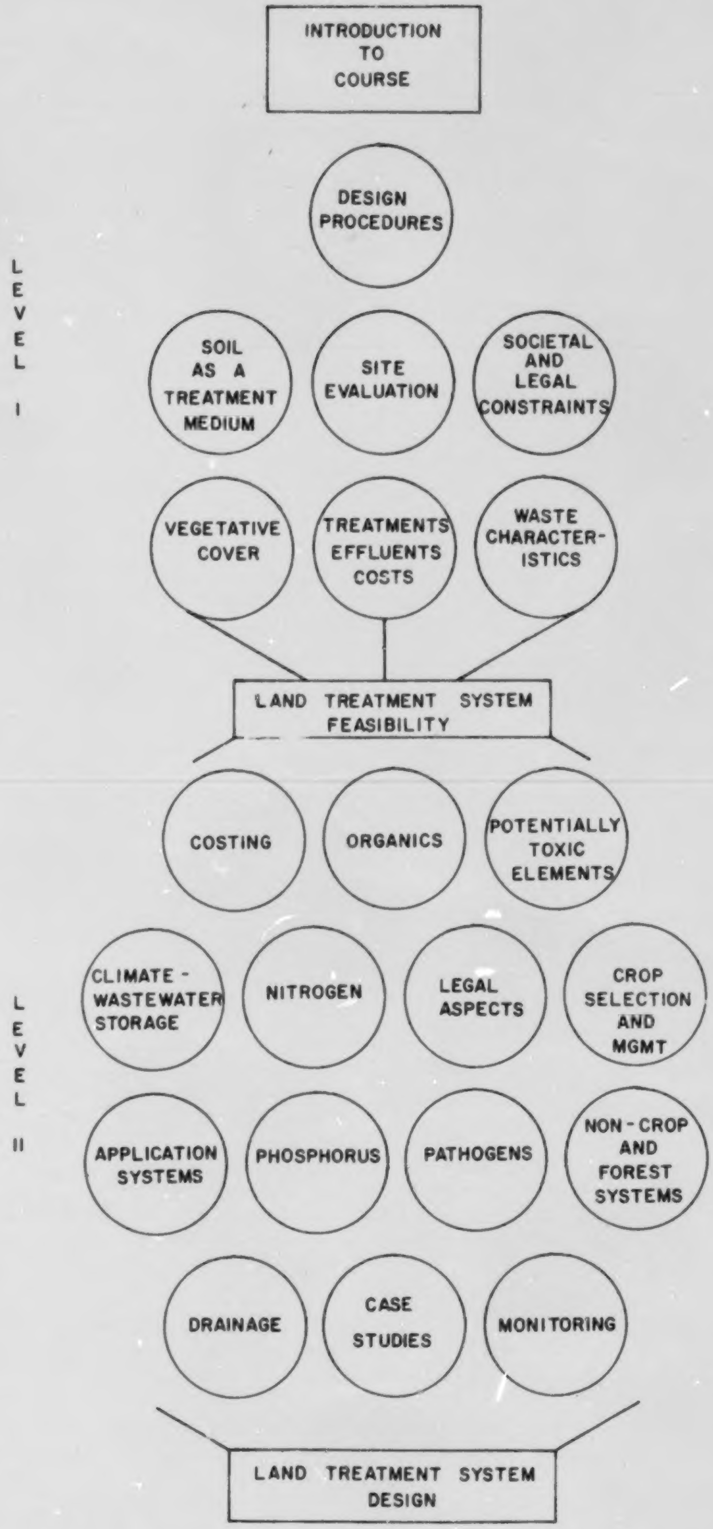
INTRODUCTION TO COURSE
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SOIL AS A TREATMENT MEDIUM
SITE EVALUATION
SOCIETAL AND LEGAL CONSTRAINTS
VEGETATIVE COVER
TREATMENTS EFFLUENTS COSTS
WASTE CHARACTERISTICS
LAND TREATMENT SYSTEM FEASIBILITY
LEVEL II
COSTING
ORGANICS
POTENTIALLY TOXIC ELEMENTS
CLIMATE - WASTEWATER STORAGE
NITROGEN
LEGAL ASPECTS
CROP SELECTION AND MGMT
APPLICATION SYSTEMS
PHOSPHORUS
PATHOGENS
NON-CROP AND FOREST SYSTEMS
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CLIMATE AND WASTEWATER STORAGE

Module 8

January, 1978

Summary

Five components of the hydrologic cycle are of utmost importance in land application systems. These are precipitation, infiltration/percolation, evapotranspiration, runoff, and groundwater. An understanding of each of these hydrologic components is necessary prior to the evaluation and design of land application systems. Hydrologic events which occur during the application season must be evaluated separately from those which occur during the nonapplication or storage season.

The application season for the site under investigation must be defined. Undoubtedly, it will include the growing season, but how far may it stretch into the spring and fall? This is dependent upon the waste characteristics, soil-plant treatment medium, and the groundwater quality required. Precipitation during the application season affects the number of application days. This interruption in the irrigation scheduling should be estimated and built into the system. Extreme rainfall events must be contained. Water sinks such as evapotranspiration, infiltration/percolation, and runoff may all be estimated. These capacities must be maximized within the limitations of the system under investigation. The soils, vegetative cover, and effluent quality are integral components in estimating these limitations.

The nonapplication season defines the storage period. Storage period is defined in terms of climatic constraints which the designer imposes on the treatment system. These constraints vary according to the location of the site and may include temperature, precipitation, snow cover, soil moisture, etc. These factors can be analyzed by computer programs developed by the National Weather Service. The programs are summarized in this module, and Appendix A is a reprint of an Environmental Protection Agency publication describing the programs and their use in detail.

Hydrologic events which affect cropping systems are not of concern during the storage period. The storage volume required is dependent upon the flow of wastewater during the storage season, rainfall into the reservoir, evaporation from the reservoir, and seepage from the reservoir. These may all be estimated with reasonable accuracy.

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Glossary

available moisture - The portion of soil water that can be readily absorbed by plant roots. Usually defined as water held in the soil against a pressure of up to 15 bars (atm).

dew point - The temperature at which air becomes saturated when cooled without addition of moisture or change of pressure.

evapotranspiration - The combined loss of water from an area by evaporation from soil, water and plant surfaces and transpiration (release of vapor) from plants.

field capacity - The moisture content which a soil will hold against the force of gravity after it has drained for 48 hours following saturation; the amount of water retained by the soil micropores.

groundwater - Water that fills all the unblocked pores of underlying material below the water table, which is the upper limit of saturation.

growing season - The period of the year when climatic conditions are favorable for plant growth, common to a given area.

infiltration - The downward entry of water into the soil.

leachate - Water which enters the groundwater from a land application site.

percolation - The downward movement of water through soil.

precipitation - Any solid or liquid water particles which fall from the atmosphere and reach the ground. Also the amount, expressed in terms of depth of liquid water, which has fallen at a given point over a specified period of time.

regolith - The unconsolidated mantle of earth above the bedrock resulting from weathering of the underlying rock and/or deposition of material transported by gravity, wind, water or ice.

soil moisture tension - The equivalent negative pressure in the soil water, equal to the pressure which must be applied to the soil water to bring it to hydraulic equilibrium, through a porous permeable membrane, with a pool of water of the same composition.

Objectives

Upon completion of this module, the reader should be able to:

1. Discuss each component of the hydrologic cycle which has an impact on land application systems. Which components are design variables?
2. Define the application season and non-application period for a given site.
3. Obtain the applicable computer program for storage requirements from the National Climatic Center, choose proper input variables, and use the output in design of storage, for a given land application site.
4. Differentiate between climatic and hydrologic factors of importance during the application and non-application periods, and perform water balance calculations for each period.

The Hydrologic Cycle

The hydrologic cycle, Figure 1, is an accumulation of many climatic and hydrogeologic phenomena which describes the cyclic nature of water movement in the natural environment. Solar energy induces the cycle through evaporation and transpiration of water from aquatic and terrestrial surfaces. Air masses collect this water vapor and transport it large distances. When the temperature and pressure of the air mass reflect the dew point, precipitation occurs. Once reaching the earth, the precipitation is either intercepted by vegetation, infiltrated into the soil profile, or accumulated in runoff to surface water bodies whereupon it is recycled.

Six components of the hydrologic cycle are reviewed, each with respect to land application systems. These include: 1) precipitation, 2) infiltration/percolation, 3) transpiration, 4) evaporation, 5) runoff, and 6) groundwater.

Several water movement mechanisms of the hydrologic cycle affect the water balance at land application sites. These factors can influence irrigation schedules, application rates, drainage design, storage design, crop selection, and other aspects of the system.

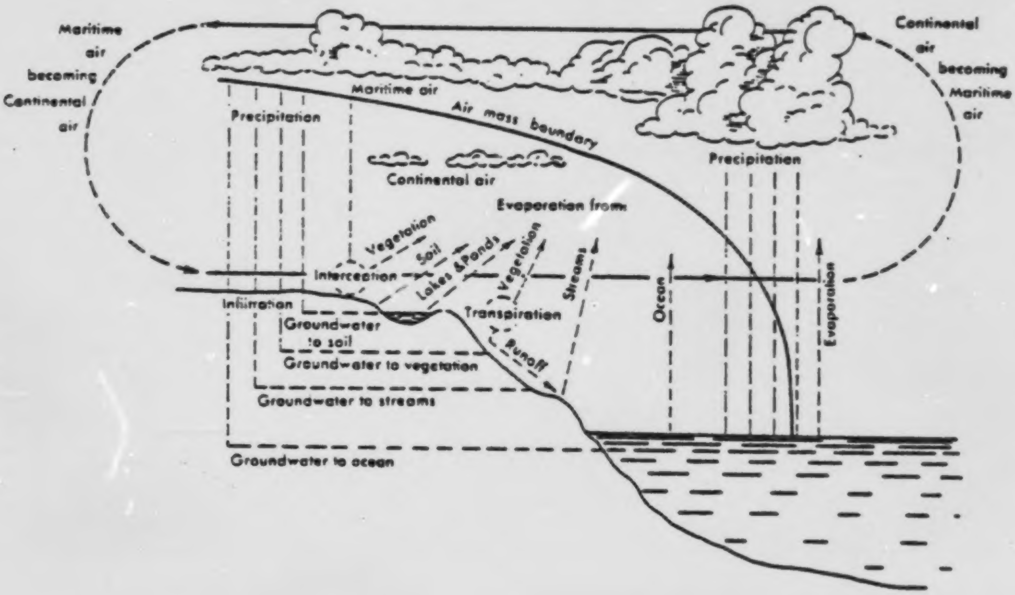

Maritime air becoming Continental air
Continental air becoming Maritime air
Maritime air
Air mass boundary
Precipitation
Precipitation
Continental air
Evaporation from:
Vegetation
Soil
Lakes & Ponds
Vegetation
Streams
Ocean
Evaporation
Interception
Infiltration
Transpiration
Groundwater to soil
Runoff
Groundwater to vegetation
Groundwater to streams
Groundwater to ocean

Figure 1. The Hydrologic Cycle ("Climate and Man", USDA Yearbook of Agriculture, 1941).

Precipitation includes all forms of moisture falling from clouds such as rain, snow, sleet or hail. Each season has an established precipitation pattern which we expect year after year. In the evaluation and design of land application systems, these precipitation patterns must be known in order that we may, 1) impose our artificial components upon the hydrologic cycle with little, if any, affect upon the surrounding ecosystem, and 2) avoid hydrologic events which may cause the land application system to fail.

Precipitation seasonal patterns may be deduced from published climatological data. They will affect application scheduling, drainage and storage design.

The infiltration and subsequent percolation of water into and through the soil profile is the major replenishment of groundwater. The variables associated with this penetration and transport of water are many, however only a few may be changed so as to enhance the infiltration capacity of the soil. These include establishment of vegetative cover and installation of graded gravel filters and subsurface drains. Penetration of water into agricultural soils generally proceeds at rates varying between 0.05 and 5 inches per hour. Application volumes and rates, e.g. 4 inches per week at 1/4 inch per hour, utilized in land application systems fall well within the general range of soil permeabilities found in irrigated agriculture. Therefore, unless unusually heavy and prolonged precipitation is encountered, hydraulic conductivity will not be a limiting factor where irrigated crops are maintained.

Infiltration/percolation rates have a bearing on process selection. For crop irrigation systems, infiltration rates are generally much in excess of application rates; infiltration/percolation capacity can be enhanced by vegetative cover, gravel filters, and underdrainage.

Evapotranspiration (evaporation and transpiration) from soil and plant surfaces varies with the soil moisture conditions, vegetative cover, and solar energy available at the site. The soil moisture condition will be increased considerably during the application season. This increase in soil moisture will also increase the evapotranspiration rate of the land application surface.

Evapotranspiration is composed of evaporation from soil and plant surfaces - a function of solar and wind energy - and transpiration - a function of plant uptake and soil moisture.

Runoff of wastewater and precipitation from land application sites must be controlled for two obvious reasons: 1) contact time between wastewater and the treatment system must be maintained to ensure removal of pollutants and 2) extreme rainfalls must be collected and routed at non-erosive flows to protect the wastewater application site from excessive soil erosion. Once collected and treated, this water may be released to stream flow.

Runoff control affects contact time of applied wastewater and possible soil erosion. Collected runoff may be returned to the head end of the treatment system.

Groundwater within the regolith replenishes water utilized through evapotranspiration, stream flow, and evaporation of large water bodies. The groundwater beneath land application sites has been protected from polluted leachates by PL 92-500, the Water Pollution Control Act Amendments of 1972. Prior to reaching groundwater levels, the leachate must meet groundwater quality criteria as outlined in PL 93-523, the Safe Drinking Water Act. Some flexibility on permissable water quality will follow from the states' interpretations of these laws. Module 16, "Legal Aspects" contains a full discussion of these points.

Groundwater quality criteria for land application sites is set out in Federal legislation.

Perhaps the two most comprehensive data sources describing the details of the hydrologic cycle for all areas of the U.S. are the U.S. Geological Survey and the National Weather Service. The U.S.G.S. is most well known for the extensive information it provides on surface water flow. Of major concern to those working on land application systems is the extensive network of wells and groundwater quality information which is also reported by USGS. This information is useful in establishing the background quality of groundwater in regions considered as potential land treatment sites. The National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) maintains approximately 3,000 weather stations across the United States. These report a variety of weather data which is accumulated and published as "Climatological Data". Precipitation data may be found in this publication

The most comprehensive data sources are the U.S. Geological Survey for surface and groundwater quantity and quality, the National Weather Service for climatological data.

as well as average monthly temperatures for use in determining evapotranspiration of the land application site. This data is valuable in determining specific storage requirements required for varying climates. Soils and cover crop information may be obtained from USDA Soil Conservation Service soil surveys, Module 2, "Site Evaluation" and Module 20, "Crop Selection and Management Alternatives".

Hydrologic Considerations in Land Application Systems

Hydrologic considerations are of paramount importance to the design, operation, and maintenance of land application systems. Wastewater is applied at a rate designed to optimize the renovation capacity of the soil/plant medium and to maximize the utilization of the available nutrients within the wastes. Unscheduled runoff events due to high intensity storms will occur over land application systems. Protection of the land from excessive erosion as well as collection of the runoff must be included in the overall design. Module 21, "Drainage for Land Application Sites", discusses these factors.

Water balance considerations are of primary concern to the design engineer. Without water, nutrient transport into and through the soil profile would be impossible. Conversely, too rapid movement may generate groundwater pollution. Water management to optimize nutrient availability in the root zone and at the same time provide for water transport at the design effluent quality is difficult with the monitoring and application equipment available today. A thorough discussion of crop water requirements is contained in Module 20, "Crop Selection and Management Alternatives". What kind of hydraulic load will the system sustain over how long a period of time and still attain the expected effluent quality? There are many variables within the soil/plant treatment medium which must be considered before a question such as this can be answered.

In developing a land application system, the system boundaries need to be defined. Once this is accomplished a hydraulic balance must be attempted to consider all avenues of inflow and outflow through the system boundaries. Figure 2 briefly outlines the considerations typically faced in the design of land application systems.

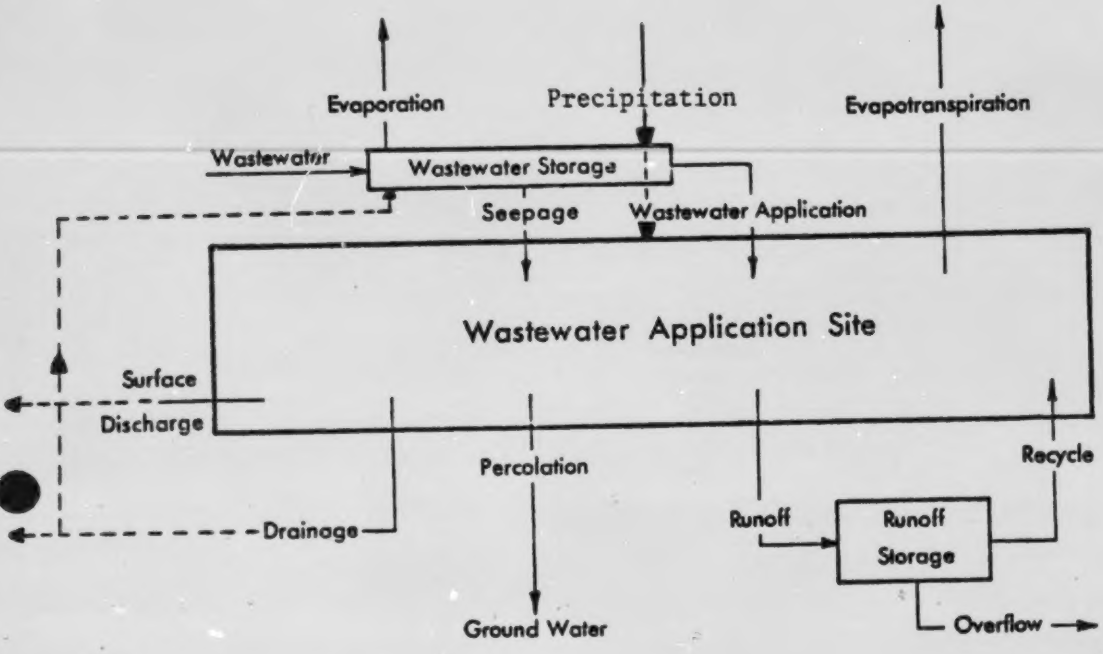

Evaporation
Precipitation
Evapotranspiration
Wastewater
Wastewater Storage
Seepage
Wastewater Application
Wastewater Application Site
Surface
Discharge
Percolation
Recycle
Runoff
Runoff
Storage
Drainage
Ground Water
Overflow

Figure 2. Hydrologic considerations in land application systems.

The hydrologic phenomena that must be considered in land application systems vary with the seasons. During the application season, such things as precipitation, evapotranspiration, runoff, infiltration/percolation, groundwater quality, and wastewater application must be taken into account in the vicinity of the application site. However, during the non-application season all wastewater is routed to storage. Hydrologic considerations for storage design include wastewater flow, precipitation, evaporation, seepage, and groundwater quality.

Hydraulic considerations differ for periods of wastewater application and storage. These periods are determined by growing season and climatic considerations.

Application Season vs. Nonapplication Periods

In determining the application design for wastewater renovation, the growing season for cover crops is of major concern where they are used for pollutant control. The growing season, as reported by USDA in Agricultural Handbook No. 283 (USDA, SRS, 1972), is dependent upon the specific crop as well as the latitude of the site. This agricultural handbook estimates the usual planting and harvesting dates of field and seed crops across the United States. The growing season, during which nutrient uptake rates are greatest at irrigation sites, is determined by climate (primarily temperature). Therefore, climatic records can be used to estimate storage requirements for land application sites by setting certain criteria for days favorable for waste application, and designating days not meeting these criteria as unfavorable or "nonapplication" days.

Computer Programs Available for Storage Volume Computation

The number of consecutive nonapplication days due to climatic constraints may be determined through the use of computer programs developed by the National Weather Service which are fully described in Appendix A. This provides a rational basis for the design of the storage requirements for any specific situation. Two programs (EPA-1 and -3) are suited to areas constrained by cold periods, and one program (EPA-2) is geared to use in wet areas. Each program uses certain variable constraints (temperature, rainfall, snow cover, etc. for cold area programs; rainfall, soil moisture condition, percent saturation, etc. for wet areas) to define favorable and unfavorable application days which are tabulated for the entire year. In the case of the cold area programs, data is given on the length and severity of cold seasons through use of the cumulative degree day tabulation. Therefore, the designer may use his discretion

Computer programs are available from the NWS, National Climatic Center that compute storage requirements based on climatic factors applicable in different parts of the U.S.

in basing storage needs on cold period length rather than on the unfavorable day analysis. The specific values of the various constraints within the program may be adjusted to meet differing design limitations. About 25 years of weather data is required at a station to obtain meaningful results from the programs. In addition to the complete description of these programs, their use and availability contained in Appendix A, further treatment of the subject is found in the audio-tutorial Module 8, "Climate and Wastewater Storage".

NWS computer programs present data on duration and intensity of cold weather along with various other climatic variables. The programs are useful design tools.

The time between the established storage period by NWS procedures and the growing season as compiled by the USDA may be several weeks to 2 months. During this time, nutrient uptake by the cover crop will be negligible. In selecting design parameters for irrigation water requirements, a mean daily temperature of 45°F has been used as the beginning and ending date of the growing season for pasture grasses (USDA, SCS, 1967). If nutrient uptake by the cover crop is to be relied upon, then the growing season limitations must be respected in the design procedure. The element of prime concern is nitrogen, since chemical precipitation of phosphorus is efficient even at low temperatures. It is also likely that problems will be minimized if the applied wastewater contains nitrogen mainly in the ammonium form. During the colder periods, adsorption of the ammonium ion will hold this form of nitrogen. As the temperature increases, nitrification may occur before plants start to grow. However, proper selection of an early growing grass crop will enable maximum nitrogen control. See Module 15, "Nitrogen Considerations", for further details.

There can be a significant lag time between the end of storage period and beginning of crop growing season. Decisions on application or storage strategy during this period depend on factors such as ammonium adsorption and establishment of early-growing grass species on irrigation sites to control nitrogen leaching.

Wastewater Application Season

Evapotranspiration rates vary with soil moisture, cover crop, and energy available. ET can be estimated by the Blaney-Criddle and other formulas.

Evapotranspiration: As mentioned earlier, evapotranspiration (ET) is the volume of water comprised of transpiration due to plant respiration and evaporation from the soil and plant surfaces. Water losses through ET can be estimated through the use of the Blaney-Criddle Formula (see Appendix B and Module 20, "Crop Selection and Management Alternatives"). In estimating the consumptive use (or evapotranspiration), the factors taken into consideration are temperature, length of day, available moisture, and the crop growth stage. Each factor varies with respect to the next resulting in a very complex expression.

The rate of evapotranspiration is dependent upon the soil moisture conditions (soil type, available moisture, soil-moisture tension), the cover crop (type of crop and stage of growth), and the energy available for respiration and evaporation (temperature and daylight hours).

With regard to the soil moisture condition, the available moisture and soil moisture tension vary as shown in Figure 3 for different soil types. As the soil-moisture tension increases, the availability of moisture for evapotranspiration decreases. In utilizing these facts in land application systems, it would behoove the design engineer to maintain as little soil-moisture tension as possible in order that the maximum amount of moisture may be available for evapotranspiration. This may come into effect in the scheduling of the irrigation period as shown in Figure 4.

In the irrigated areas of the United States, irrigation scheduling is a topic of great importance among farmers, soil-crop specialists, and irrigation engineers. The farmers and soil-crop specialists rely upon delivery of water to the irrigated crops between specified limits, i.e. field capacity and approximately 50% of field capacity.

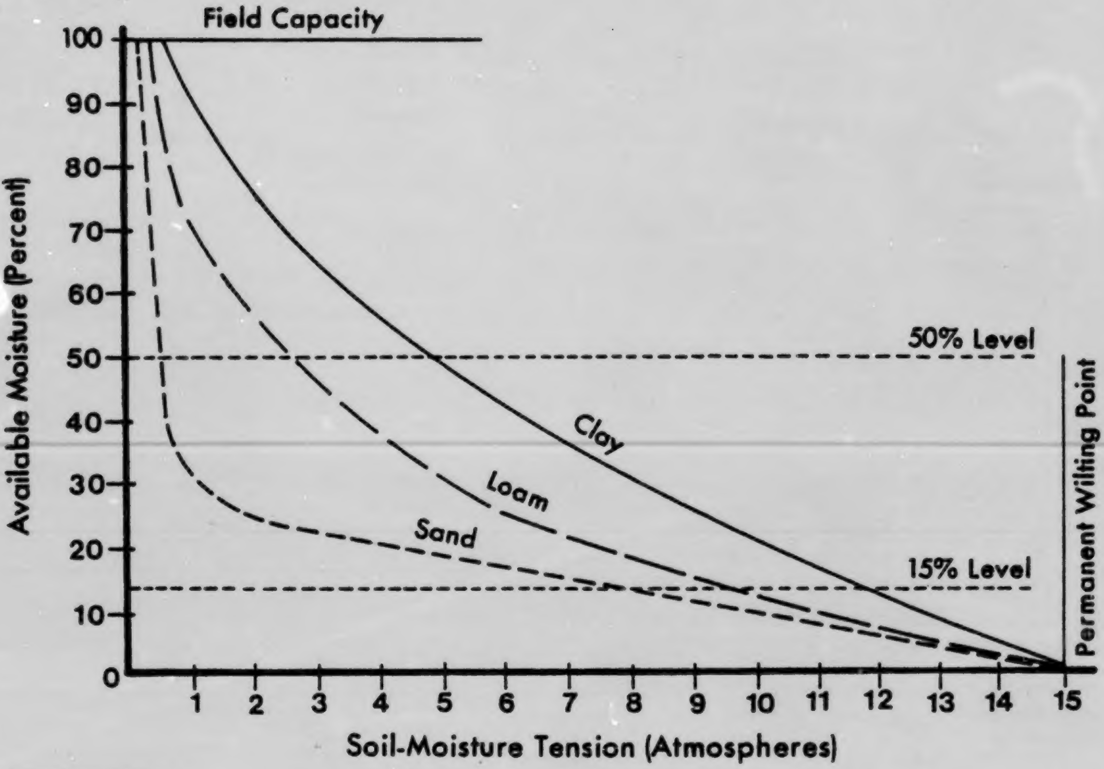


Figure 3. Moisture-release curves for three soils (Thorne and Raney, 1956).

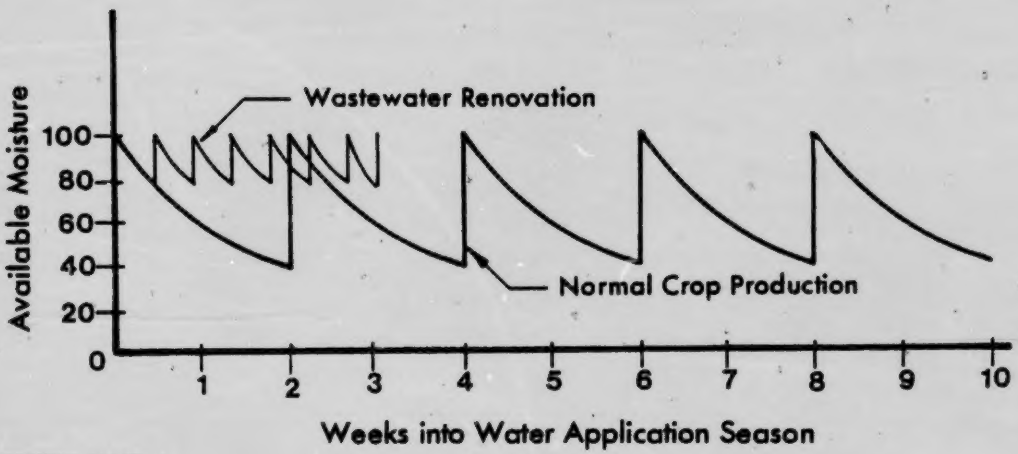


Figure 4. Irrigation scheduling at shorter intervals will maintain a higher percentage of available moisture in the soil profile for evapotranspiration.

In this manner, water is delivered to the crop prior to the occurrence of plant stresses which would decrease productivity. This approach for water replenishment was developed around a shortage of water. However, in land application systems, the object is to maximize the flow of water, therefore irrigation scheduling techniques which maximize this water sink (evapotranspiration) should be developed. Scheduling water delivery when approximately 20% (80% field capacity) of the available moisture is depleted will maximize the evapotranspiration potential of the site.

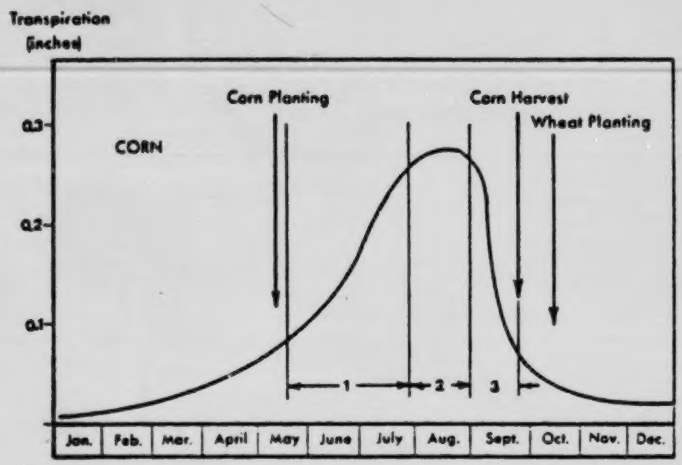
Scheduling wastewater application at soil moisture not less than 80% of field capacity will maximize uptake due to ET. Normal irrigation practice (to conserve water) is to apply at about 50% field capacity.

Certain management schemes in the humid northeast and southeast will probably include wastewater applications when soil water is at field capacity. By applying the water at a slow rate the macropore space can remain free of water and provide the aeration needed for a healthy soil.

Continuous high moisture conditions within the root zone may jeopardize many cropping systems, especially if anaerobic conditions occur. Reed canarygrass has come to the forefront in land application systems because of its high moisture tolerance. Additional data on water tolerance of other crops are discussed in Module 20, "Crop Selection and Management Alternatives".

The type of crop cover selected for wastewater renovation will depend on many variables. Perennial crops vs. annual crops is the first division where a decision must be made. Perennial crops provide year-round soil cover, protecting the land application site from excessive erosion. Annual crops can provide high peak nutrient uptake during certain periods, as discussed below. Many successful systems employ a combination of annual and perrenial crops. The pros and cons of various cropping systems are discussed in Module 20.

Other things being equal (soil moisture and available energy), evapotranspiration from the cover crop is largely dependent upon the stage of growth and is more apparent with annual crops than perennials. Figure 5 outlines three stages: 1) emergence and development of a complete vegetative cover which generally proceeds over 1/2 of the growth period; 2) a period of maximum vegetative cover where evapotranspiration is also at a maximum; and 3) crop fruiting and maturing where evapotranspiration begins to drop off.



1) emergence and development
2) maximum vegetative cover
3) crop fruiting and maturing

Figure 5. Evapotranspiration is a function of climate, soil moisture, and crop characteristics. These results are for irrigated crops under similar climatic conditions in Ohio; observed differences are due to crop (adapted from Soil Conservation Service, 1964).

The energy available for evapotranspiration is not a design variable for any given site, but is a function of local climatic conditions. Air temperature and number of daylight hours are two easily measured and widely reported variables which may be used to compute the total energy for ET. This is explained at length in the discussion of the Blaney-Criddle Formula, Appendix B. Other formulas for ET calculation, and a general discussion of their usefulness, are included in Module 20, "Crop Selection and Management Alternatives".

In summary, evapotranspiration rates are dependent upon the soil moisture condition, cover crop, and energy available for evaporation and transpiration. The soil moisture condition and the cover crop may be manipulated to maximize the evapotranspiration from the energy available at the site.

Seasonal consumptive use (ET) averages between 1.5 and 4.0 ac-ft/ac-yr depending upon the many factors previously outlined. The higher values would be expected from the irrigated areas of the Southwest, whereas the lower would be more representative of the cooler Northeast.

Precipitation: Precipitation over the land application site has a relatively minor negative effect on the volume of water that may pass through the system, and it would have a slight positive effect through dilution of nutrients and mineral salts. However, precipitation which induces erosive flows within the land application site may be quite damaging to the physical system. The site must be guarded against these extreme rainfall runoff events. The most common controls against runoff include diversion structures, terraces, and waterways which collect and deliver the runoff water to storage at non-erosive flows.

The most important factor concerning precipitation is control of flow from unusually heavy storms.

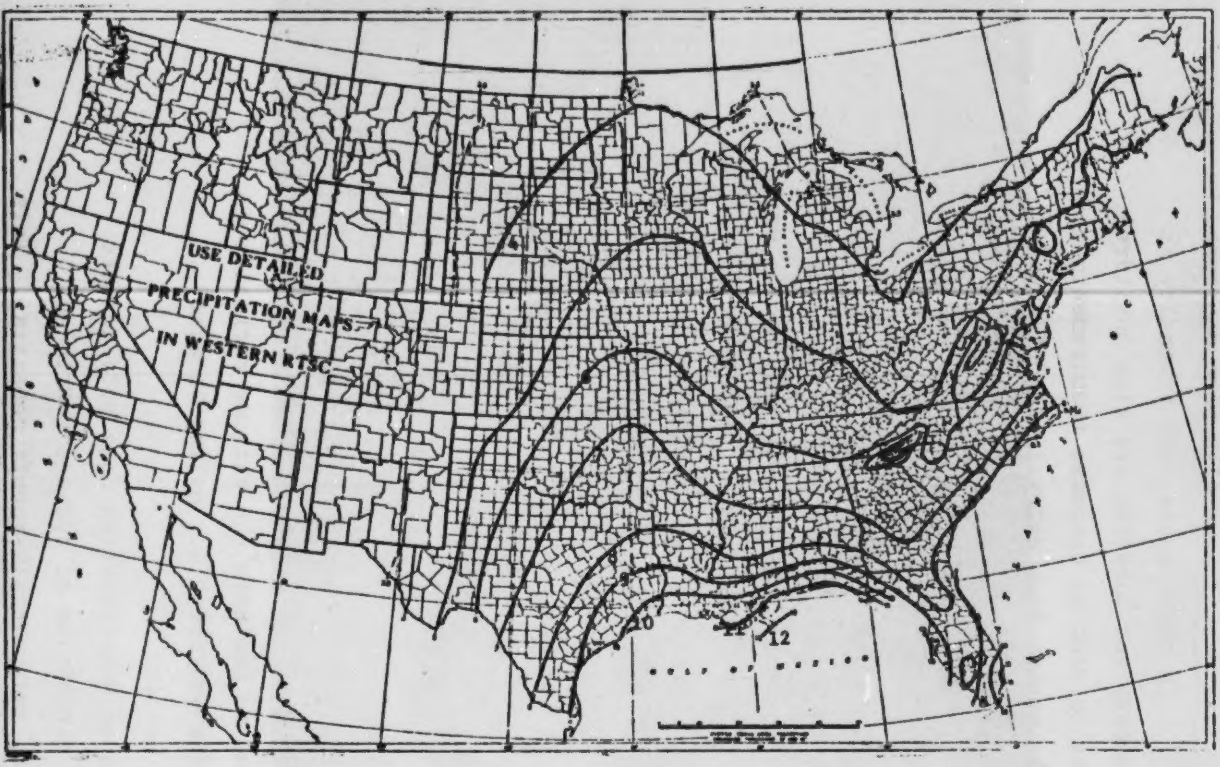
The average monthly precipitation is an accumulation of normal rainfall events which occur over an hour or two or possibly whole days. These few days of rain could upset the irrigation scheduling if they occurred so as to postpone the application day. The number of potential days postponed should be evaluated and included in the irrigation scheduling. The infiltration/percolation capacity of the soil profile must be matched against typical rainfall events over the application season to estimate the number of nonapplication days expected. However, where runoff from the site is not expected and where the vegetative cover permits, rainfall will dilute any additional wastewater application.

Climatological data published by the National Weather Service gives daily precipitation as well as average monthly and yearly precipitation. Whiting (1975) reviews the climatic data available from the National Weather Service.

Extreme rainfall events have also been monitored by Hershfield (1961). In these cases, the intensity as well as the frequency and duration are also monitored. This type of data is used to estimate requirements for protection of the system from excessive erosion and component failure, i.e. terraces, dams, pipes, channels, diversion ditches, etc., during high rainfall-runoff events.

The frequency for the chances of a storm occurring in 2, 5, 10, 25, 50 and 100 years and having a duration of 6, 12, and 24 hours are detailed on maps of the United States. Figure 6 is one map taken from Hershfield (1961). This map indicates 25-year, 24-hour frequency and duration storms only. This data can serve as a basis to design an ecceptable level at which runoff from a site would be deemed to be unavoidable by the regulatory agency. Thus runoff would be contained from a 6 inch precipitation event that occurred over a 24 hour period. But any amount exceeding 6 inches could be acceptable runoff. More precise maps for the western states are available from the Soil Conservation Service within those states. Figure 7 is a detailed map of Colorado, which is included to indicate the extreme variability of rainfall in the western U.S., making broader generalizations useless.

These kinds of precipitation data help to make possible design estimation of average yearly and monthly rainfall, and rainfall-runoff potential. This is considered as basic information to this type of engineering design.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PRECIPITATION MAPS
IN WESTERN RTSC
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Figure 6. 25-year, 24-hour rainfall of the Eastern United States (Hershfield, 1961).

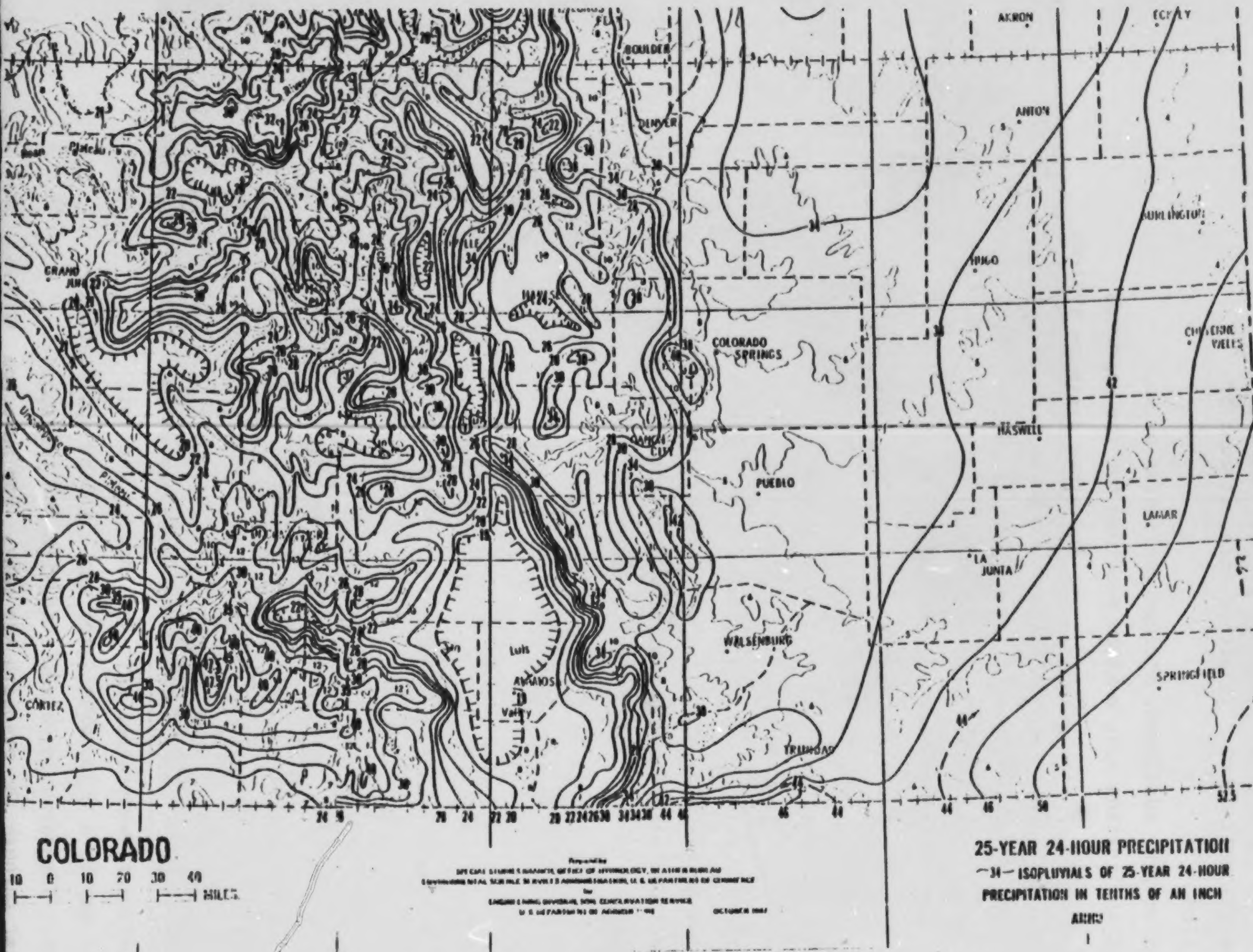

COLORADO
10 0 10 20 30 40 MILES
BOULDER
DENVER
AKRON
ECKLEY
ANTON
BURLINGTON
HUGO
GRAND JUNCTION
COLORADO SPRINGS
CHEYENNE WELLS
HASWELL
PUEBLO
LAMAR
LA JUNTA
WALSENBURG
SPRINGFIELD
CORTEZ
TRINIDAD
San Luis Valley
25-YEAR 24-HOUR PRECIPITATION
—34— ISOPLUVIALS OF 25-YEAR 24-HOUR PRECIPITATION IN TENTHS OF AN INCH

Figure 7. 25-year 24-hour rainfall of Colorado (SCS, 1971).

Runoff: Runoff from land application sites may be part of the wastewater renovation process as in overland flow systems, or it may occur as the result of an extreme rainfall event. In either case, it must be controlled.

In design, additional storage facilities as well as land application area must be provided for the expected runoff events. Where combined sewer and urban drainage systems are used, the land treatment system must be capable of storing and applying not only sewage but also nonpoint source urban runoff. Runoff controls from the land application site must also be provided to preclude nonpoint source runoff of nutrients, pathogens, sediments, etc. and to protect the capital investment in the land application system from excessive erosion. Erosion control measures may include such things as terraces, diversions, grassed waterways, drop structures, detention reservoirs, etc. All of these soil and water conservation measures are used either to store excessive water in place, transport water at non-erosive flows, or store water after being safely transported.

Runoff can produce erosion and unwanted discharge of nutrients and pollutants to surrounding land or watercourses. Typical drainage structures are used to control runoff; these must be sized to accommodate a design storm flow.

The 25-year 24-hour storm is used as the precipitation event from which all runoff must be contained for open beef cattle feedlots. Generally the nutrient and microorganism level on an active feedlot surface would be much higher than that of a land application system. The nature and the source of the wastewater being applied is an important factor in selecting runoff control criteria. The unchlorinated effluent from preliminary treatment would certainly have more stringent controls than that from a pea processing plant.

Infiltration/percolation: The infiltration and percolation of wastewater into and through the soil profile may be a major wastewater sink in land application systems. The variables associated with the transport of water through the regolith are many. For purposes of this discussion, it is assumed that no extraordinary avenues of escape are available which will allow the wastewater to short circuit the soil treatment medium. Careful investigation of the treatment site must be undertaken in order to preclude this from happening. Potential problems which may arise from short circuiting and prevalent regolith configurations which enhance its occurrence are discussed in Module 2, "Site Evaluation".

Infiltration and percolation of wastewater into the soil is important in most land treatment systems. Site evaluation must assure that this mechanism is not short-circuited by subsurface faults.

Permeability values for many soils are listed within the local soil survey or irrigation guide developed by the USDA Soil Conservation Service. These values are generally obtained from a simple clean water infiltrometer test although an explanation of the procedure used is generally provided in the accompanying text. Table 1 briefly outlines the Soil Conservation Service classification system from which the permeability class in the soil survey is obtained.

Table 1. Permeability classes for saturated soil (USDA-SCS, 1971).

Permeability Class	Inches Per Hour
Very slow	less than 0.06
Slow	0.06 to 0.20
Moderately slow	0.20 to 0.60
Moderate	0.60 to 2.0
Moderately rapid	2.0 to 6.0
Rapid	6.0 to 20
Very rapid	more than 20

Generalized tables of infiltration ranges based upon textural class are also available, as given in Table 2. The variability in the approach and comparative values found in such tabulations emphasize the need for on site evaluation of this design parameter.

Table 2. Typical ranges of infiltration rates and available soil moisture by soil textural class (Powell, 1975).

	Available Soil Moisture Storage(1)		Good Condition Base Soil Basic Infiltration Rates(2)		
				Slope	
	Range	Average	0-3%	3-9%	9+%
	---------in/ft---------		------------in/ft-----------		
Very coarse textured sands and fine sands	0.50-1.00	0.75	1.0+	0.7+	0.5+
Coarse textured loamy sands and loamy fine sands	0.75-1.25	1.00	0.7-1.5	0.50-1.00	0.40-0.70
Moderately coarse textured sandy loams and fine sandy loams	1.25-1.75	1.50	0.5-1.0	0.40-0.70	0.30-0.50
Medium textured very fine sandy loams, loams, and silt loams	1.50-2.30	2.00	0.3-0.7	0.20-0.50	0.15-0.30
Moderately fine textured sandy clay loams and silty clay loams	1.75-2.50	2.20	0.2-0.4	0.15-0.25	0.10-0.15
Fine textured sandy clays, silty clays and clays	1.60-2.50	2.30	0.1-0.2	0.10-0.15	<0.10

(1) Storage between field capacity (1/10 to 1/3 atm) and wilting point (15 atm).

(2) For good vegetative cover these rates may increase by 25 to 50%. For poor surface soil conditions these rates may decrease by as much as 50%.

It must be pointed out that infiltrometer tests and other infiltration/percolation estimates are based upon the flow of clear water. Secondary treated effluent nearly matches this as far as hydraulic conductivity is concerned. Even raw sewage which has been exposed to preliminary treatment has less than 0.5% solids. Clogging of the soil profile is not likely with these types of effluents in systems other than rapid infiltration/percolation. But where sludges are separated from the wastewater stream and concentrated, their solids content is appreciably increased. Heavy applications of this type of material may cause soil clogging, but scheduled rest periods have kept this problem at a minimum.

Hydraulic conductivity, measured by soil infiltration and permeability, should not be limiting except in high rate rapid infiltration systems. Liquid sludge application systems may require evaluation to determine if clogging may be a problem.

When comparing the soil permeability (Table 1) with typical wastewater application rates (2 to 60+ inches per week), it is easy to see that the hydraulic conductivity of the soil will rarely be a limiting factor except for rapid infiltration/percolation systems. Once the wastewater has infiltrated the soil, the percolate below the treatment medium must be acceptable quality, as defined by applicable laws or standards. In most cases at 5 feet into the soil profile, land application systems will have to produce water quality that will meet drinking water standards.

Groundwater quality at a proposed site may affect pretreatment requirements, establishes the necessary baseline to measure system performance, and assists in planning site management.

Groundwater: As mentioned previously, groundwater quality is protected from degradation by national and local laws. The quality of groundwater must be known prior to wastewater application for several reasons: 1) degradation of groundwaters beyond specified limits will not be allowed, therefore some pollutants may have to be removed entirely prior to wastewater application to the land, i.e. nitrates leached to nitrate laden groundwaters, 2) proof of the source of groundwater contamination, if and when it occurs, must be established for remedial as well as legal reasons, and 3) knowledge of the groundwater quality prior to operation of the land treatment system will assist in making management decisions.

A system of monitoring the quality and movement of groundwater must be established to provide the background information needed for quality assurance and design base. Monitoring of the groundwater is discussed in Module 18, "Monitoring at Land Application Sites".

Wastewater Application: Some of the soil and vegetative responses to land application of wastewater are predictable. This area of concern has been researched from the cropping systems standpoint as well as the wastewater renovation standpoint.

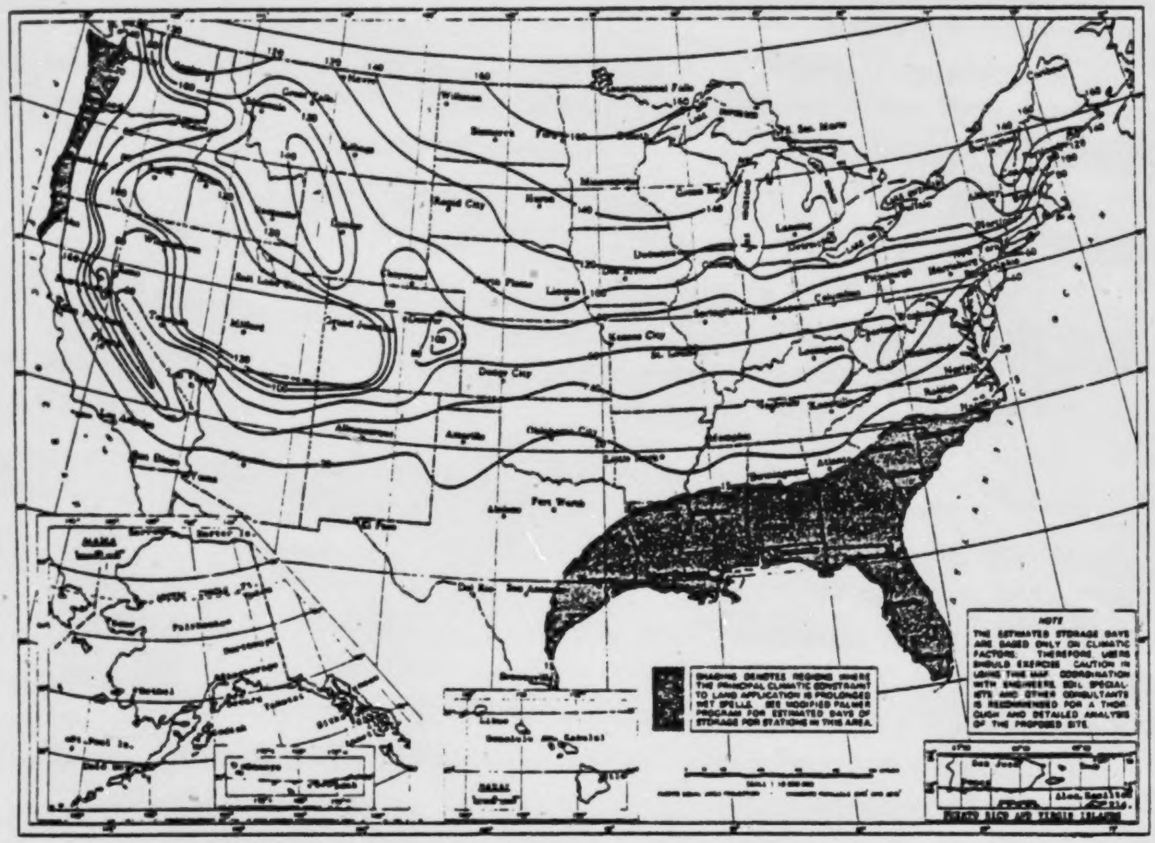
In many soils, the bulk density increases appreciably when large volumes of water are applied over short periods of time. This increase in bulk density is at the expense of soil macroporosity which, in turn, results in substantial decreases in infiltration capacity, aeration, and plant productivity (Keller, 1970). Low application rates, less than 0.2 inches per hour, over longer periods of time allow the water to pass through the soil profile without exhausting the air from the macropore space. In wastewater distribution systems, this would also allow more time for evaporation to extract additional water from the spray.

Heavy water application can affect soil macroporosity. Vegetation may be established because of its water tolerance or allowed to adapt naturally.

Some types of vegetation have an established tolerance for high moisture conditions. Where prolonged moisture conditions prevail, vegetative cover will change and adapt to the new soil moisture extremes and where additional water is imposed upon the hydrologic cycle, a vegetative change should be expected. Water tolerant forage crops such as reed canarygrass are popular for that property. Vegetative change may be realized through purposeful planning and design for re-vegetation or this may be left to dominant species take-over at the site. In any case, a vegetation change should be expected and investigated in planning and design of land application systems.

Nonapplication Season

Wastewater Storage: The storage capacity of effluent required in land application systems depends upon the incoming wastewater rate and the number of consecutive unfavorable application days over the year. An extensive study of climate and weather variations has enabled general predictions of the storage requirements for all portions of the U.S. to be estimated by use of the NWS computer programs discussed earlier (see Appendix A). A summary of this study is shown in Figure 8. For New York State, the average number of nonapplication days for which storage would normally be required is around 120 days. All additions or deletions from the storage system must also be considered. These include such things as precipitation, evaporation and seepage into or out of the reservoir.



▨ SHADING DENOTES REGIONS WHERE THE PRINCIPAL CLIMATIC CONSTRAINT TO LAND APPLICATION IS PROLONGED WET SPELLS. SEE MODIFIED PALMER PROGRAM FOR ESTIMATED DAYS OF STORAGE FOR STATIONS IN THIS AREA.

NOTE

THE ESTIMATED STORAGE DAYS ARE BASED ONLY ON CLIMATIC FACTORS. THEREFORE USERS SHOULD EXERCISE CAUTION IN USING THIS MAP. COORDINATION WITH ENGINEERS, SOIL SPECIALISTS AND OTHER CONSULTANTS IS RECOMMENDED FOR A THOROUGH AND DETAILED ANALYSIS OF THE PROPOSED SITE.

Figure 8. Storage days required as estimated from the use of the EPA-1 computer program as described in Appendix A.

Storage design factors include length of nonapplication season, wastewater flow, precipitation, evaporation, and seepage.

The flow of wastewater from municipalities varies considerably not only during the day, but also over the seasons. These variations are due to many activities, each differing, depending largely upon the climatic conditions of the area, the seasonal influx of people, etc. Sewers collecting raw sewage are often far from watertight. The quality control during construction and the ground movement after construction is such that inevitably cracks occur along cemented pipe joints. During the seasons where a high water table is to be expected, seepage into the sewers adds to the base flow. Of course this base flow fluctuates during the year. The seasonal fluctuation of population such as students, tourists, etc. also places an extreme variation on the waste treatment facility. The volume of wastewater derived from municipalities varies between 70 to 150 gallons per capita per day. This depends largely upon the population density, commercial and industrial dischargers, and the seasonal water table which encourages seepage into the system.

The precipitation which falls directly into the storage facility must be applied to the land during the wastewater application season. The design values selected for this parameter should be taken from local climatological data from the nearest NWS reporting station. This accumulation could account for appreciable amounts of water especially in areas of the country where precipitation greatly exceeds evaporation.

Evaporation from the storage reservoir occurs throughout the year, varying from 20 inches per year in Maine to 86 inches per year in Arizona. Evaporation losses from reservoirs could be a substantial water sink, however total dissolved solids accumulate in the remaining wastewater. Two factors which minimize the effect of evaporation from storage are 1) in cold areas, storage ponds are full during low evaporation periods, and 2) in high evaporation areas like Arizona, storage needs are very small.

Seepage of wastewater from the storage reservoir will no doubt be kept at a minimum due to laws and regulations. Impermeable reservoir linings are available but expensive. Where a water table is reasonably close to the reservoir bottom, interceptor drains such as those at Muskegon, Michigan may be used to capture the wastewater for recycle to the reservoir. Whether or not the bottom of a reservoir handling organics seals itself is an unanswered question. For all practical purposes, tight soils in reservoir bottoms will seal, sands and gravels may never seal. In most systems it is assumed that the net transfer of water out of the storage facility due to seepage will be zero. In cases where seepage cannot be avoided, recovery of the seepage and recycle to storage is one acceptable control alternative.

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APPENDIX A

USE OF CLIMATIC DATA IN ESTIMATING STORAGE DAYS FOR SOILS TREATMENT SYSTEMS

By

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DISCLAIMER

This report has been reviewed by the Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ABSTRACT

The number of days each year that Soils Treatment Systems may be inoperative because of unfavorable weather conditions can be estimated from analysis of daily climatological data. In cold regions each winter season (Nov.-Apr.) is examined for a 20- to 25-year period. Each day is defined as favorable, partly favorable or unfavorable using a set of thresholds for temperature, precipitation and snow depth. A daily accounting procedure adjusts the increase or decrease in storage on the basis of the type of day and the drawdown rate. The maximum storage days each year are summarized in a final table which also presents the mean, the standard deviation, the unbiased third moment about the mean, the coefficient of skewness and storage days for recurrence intervals of 5, 10, 25 & 50 years.

A separate program is used for stations in wet regions where the primary constraint to land application is saturated soil. The daily mean temperature and precipitation are examined for a 20- to 25-year period using the modified Palmer program. This program estimates the condition of both the underlying and surface soil layers in an attempt to identify periods when saturation occurs and runoff would result from additional precipitation or application. The longest consecutive period of unfavorable days each year is summarized in a table that also shows estimated storage days at the 5, 10, 25 & 50th percentiles.

Chronological listings of the actual data and computations for the entire period of record can also be furnished. Thresholds of most of the parameters can be changed to suit individual systems. The program can also be modified to examine the condition of the surface layer during the growing season as an estimate of irrigation needs.

This report is submitted in fulfillment of Interagency Agreement EPA-IAG-D5-F694 by the National Climatic Center, Asheville, North Carolina. Work was completed on June 30, 1976.

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CONVERSION TABLES

ENGLISH TO METRIC UNITS

Length:

1 inch (in.) = 25.4 millimeter (mm.)
= 2.54 centimeter (cm.)

1 foot (ft.) = 30.48 centimeter (cm.)
= 0.3048 meter (m.)

1 yard (yd.) = 91.44 centimeter (cm.)
= 0.9144 meter (m.)

1 statute mile (stat. mi.) = 1609.344 meter (m.)
= 1.609344 kilometer (km.)

Speed:

1 mile per hour (mi. hr.$^{-1}$, mph) = 0.868391 knot (kt.)
= 0.44704 m. sec.$^{-1}$
= 1.609344 km. hr.$^{-1}$

Density, Specific Volume:

1 pound per cubic foot (lb.ft.$^{-3}$) = 0.0160185 grams per cubic centimeter (g.cm.$^{-3}$)

Pressure:

1 standard atmosphere (14.7 lbs. in.$^{-2}$) = 760 millimeters of mercury (mm.Hg.)

1 millibar (mb.) = 0.750062 millimeters of mercury (mm.Hg.)

Temperature:

Celsius (C) = 5/9 (F-32) where F is temperature in degrees Fahrenheit

Absolute (A) or Kelvin (K) = C + 273.16

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Appreciation is also extended to the Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma for its support of this project, and especially to Mr. Richard E. Thomas, Project Officer.

Special recognition is extended to Dr. J. R. Mather, Wayne C. Palmer and others for their work in developing many of the techniques used in these programs. The concept of assessing the water balance in the general manner described was developed by the late C. W. Thornthwaite.

SECTION I

CONCLUSIONS

Engineers, planners, and designers of Soils Treatment Systems may need an estimate of the number of days when land application would be undesirable due to certain weather conditions. If storage must be planned during extended periods when application would result in surface runoff, the programs developed can be used to estimate the duration of such conditions. In addition, the modified Palmer program (EPA-2) might be useful in estimating irrigation needs during the growing season.

The programs developed by the National Climatic Center, through support of the Environmental Protection Agency, provide estimates of storage requirements using 20 to 30 years of daily climatological data. Two of them (EPA-1 and EPA-3) are designed for use at stations in cold regions, while another (EPA-2) is best suited to those in wet regions. The EPA-3 program is similar to EPA-1 but examines daily maximum and minimum temperatures instead of the daily mean temperature. In this program an unfavorable (UNF) day is defined as one with precipitation of one-half inch or more, snow depth one inch or more, or a maximum temperature less than 40°F. A favorable (FAV) day is one with less than one-half inch precipitation, snow depth less than one inch, a maximum temperature of 40°F or more and a minimum temperature of 25°F or more. Partly favorable (L) days have less than one-half inch precipitation, less than one inch of snow on the ground, maximum temperatures of 40°F or more, but with minimum temperatures less than 25°F. On FAV days the decrease in storage is equal to the daily flow (Q) minus the drawdown rate (DD). On 'L' days, the increase (gain) in storage is equal to Q-(DD/2), while on UNF days the increase in storage is equal to Q.

A final summary of EPA-3 includes the yearly storage values from which the mean, standard deviation and other statistics are derived. Finally, the estimated storage days are computed by the Pearson Type III method for recurrence intervals of 5, 10, 25 and 50 years.

The programs represent a rather simple approach to a complex problem. They deal almost exclusively with climatological factors rather than biologic or hydrologic ones. In spite of the great variability in soils, climate and waste characteristics, reasonable estimates of storage requirements due to climate can be obtained from daily climatological records.

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Estimates derived from these programs should be examined carefully to determine if adjustments are necessary because of local conditions. No program can account for all possible variables such as the quality and concentration of the effluent, depth to water table, soil type and condition, loading rates and others.

Hill [1] points out that the Thornthwaite method for estimating evapotranspiration from the mean daily temperature and length of day is generally conceded to be a poor estimator for daily amounts. However, it appears that in identifying wet spells neither evapotranspiration nor the available water capacity of the soil significantly affects the results; that is, when rainy spells occur, the amount of rainfall is sufficient to saturate the soil regardless of its assigned capacity.

Estimates from EPA-2 based on 25 years of record for stations in wet regions do not always fit a smooth pattern. Estimates range from 11 to 35 days in Louisiana, 12 to 33 days in Mississippi and 21 to 165 days in Oregon. The greatest number of storage days due to saturated soil occurs along the coast of Washington and Oregon.

A modification of EPA-2 examines the runoff and the condition of the surface and underlying soil in defining unfavorable days. Additional modification might be advisable in order to classify days as unfavorable unless the computed soil moisture is lower than the proposed loading rate. There are times when runoff is not indicated yet the underlying layer (SU) is saturated and the surface layer (SS) is within a few hundredths of an inch of being saturated. The program can be altered to class such days as unfavorable. This feature is identified on the listing by a percent following the EPA-2 indicator; for example, EPA-2(10%) denotes a set of data processed using not only the runoff feature in defining unfavorable days, but includes those days when the sum of the surface (SS) and underlying (SU) layers is within the indicated percent (10) of saturation. Of course, saturation is defined as the assigned available water capacity (AWC) for that location. This feature has the effect of extending the wet spells between a series of days with runoff. It can also be useful in estimating irrigation needs during the growing season since the moisture in the surface layer is indicative of the amount available in the root zone. It should also prove useful in estimating, along with other factors, the maximum loading rate during certain times of the year.

Finally, the variability in the amount of storage needed from year-to-year can be significant at some stations. For example, standard deviations of 15 to 20 are common at stations having a mean of 45 storage days. The yearly storage values can be used as input to the Gumbel extreme value analysis which gives estimates of storage days for return periods up to 100 years with confidence bands of ± 34%.

SECTION II

RECOMMENDATIONS

The programs defined as PO3B75:NCC-EPA-1 or EPA-3 generally should be considered at sites where the normal January temperature is colder than 40°F (4.4°C), while SOILMT:NCC-EPA-2 should be used in areas where the normal annual precipitation is 50.00 inches (1266 mm) or more. The selection of these arbitrary thresholds was made after processing a number of stations on both programs. The transition zones are not clearly defined and the 40°F temperature and the 50 inches of precipitation are only rough approximations. It may be desirable in some cases to process the data both ways, especially in the Pacific Northwest.

Each program was developed to accept variable thresholds which can be changed to account for differences in soils, systems, etc.; however, the basic programs remain intact. Sharp differences in temperature, precipitation, and soil can occur over very short distances, hence each site should be examined on an individual basis. Consultation with hydrologists, geologists, soil scientists, and other specialists is highly recommended.

SECTION III

INTRODUCTION

A need was expressed in 1974 by the Robert S. Kerr Environmental Research Laboratory, Environmental Protection Agency, to find a way of using climatic data to estimate storage days for Soils Treatment Systems. Some thought was given to using soil temperature and soil moisture measurements, but this was not possible because of the paucity of data. The programs developed at the National Climatic Center (NCC) require serially complete, long-term digitized data. This type of daily climatological data is available for many locations in the NCC's tape library.

Once the data base had been selected, it was necessary to determine just what constituted climatic constraints to land application. It soon became apparent that a constraint for one system and location often was not a constraint elsewhere. In addition, while cold and snow might be definite constraints in some regions, prolonged rainy spells would be the major deterrent in others. Add to these variables the different types of soils, systems, types of effluents, etc. and one can sense the misgivings with which this project was started.

There were one or two hopeful signs. First, if the user can specify the types of weather unfavorable for a particular operation, those days can be identified. Second, Palmer's program [2] to identify droughts might be modified to define days when the soil was saturated and runoff would occur. The development of these programs provided a method of estimating storage days in cold and in wet regions. Only experience and observation will reveal how well these programs work. No field tests or controlled studies have been made; however, continued alterations are being made to the programs.

Each program can accept variable input, i.e. different thresholds, in order to be of maximum use. The basic programs remain standard, while the adjustment factors can be changed to account for the variations in soils, systems and climate. As a first approximation these programs are being used with a set of threshold values which are applicable for wastewater irrigation systems. Thresholds applicable for high-rate infiltration systems and overland-flow systems will be developed later.

The U. S. Army Corps of Engineers has done a vast amount of research in connection with soil trafficability. Much of their investigative work [3] is geared toward developing programs that can predict the state of the soil at a given time and place. Other efforts have been centered on the prediction of stream flow and with the hydrologic quality of soils [4]. Nothing in the literature examined dealt with the problem of identifying the frequency or duration of periods when the ground was saturated, although a number of studies [5-12] examined the water balance during the growing season.

The soil type and its condition more than any other factors generally determine the amount of runoff. The Soil Conservation Service (SCS) has completed surveys in many areas and has published detailed information for various soil series that may be obtained at local SCS offices [13].

Although the available water capacity (AWC) may not be a major factor in the programs discussed, it is an important soil property for other reasons. It is often given in reports as estimated amounts of water, in inches per inch of soil for specific soil layers. The following adjective ratings refer to the sum total of available water from the surface to bedrock, or to a depth of 60 inches.

Very Low	< 3 Inches
Low	3 to 6 Inches
Medium	6 to 9 Inches
High	9 to 12 Inches
Very High	> 12 Inches

The four major hydrologic soil groups, as described by the Soil Conservation Service, are presented here for information.

A. (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted. These consist chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission in that water readily passes through them.

B. Soils having moderate infiltration rates when thoroughly wetted. These consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Soils having slow infiltration rates when thoroughly wetted. These consist chiefly of soils with a layer that impedes downward movement of water or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

D. (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted. These consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The programs developed at the NCC appear to follow actual physical processes rather well, at least as far as climatology is concerned. The depletion rate in EPA-2 was introduced to offset a unique condition in Palmer's original program. It can best be explained by saying that his weekly and monthly accounting systems had no provision to carry-over runoff. In the daily accounting, it became necessary to gradually deplete the excess defined as runoff. Since only a percentage of the surplus water runs off on any day [13], it was necessary to assign some estimated amount to account for gravitational water that is made available as runoff in the following days. The amount lost each day depends on, among other things, soil type, structure, and depth of the soil layer.

It became clear that any attempt to introduce all of the variables affecting storage was either not possible, or not justified on the grounds of time and money. An empirical approach seemed to offer a reasonable escape from this dilemma. Stations with different soil groups (clay, loam, and sand) were processed using assigned depletion rates (.50, .75, and 1.00 inch per day, respectively). The only guide used in selecting these numbers came from experience and observation. For example, if the indicated amounts fall on saturated soil it will very likely take at least one day for that particular soil to dry enough so that application is possible. The programs discussed in this report use limited input data in an attempt to attain certain objectives. Most of the development discussed in the report focuses on irrigation-type systems whose operation is influenced much more by precipitation than by either overland-flow systems or high-rate infiltration systems.

One of the obvious limitations in this report is in the area of hydrology. None of the programs discussed in this report provide information dealing with the intensity, duration or amount of precipitation from individual storms. The Office of Hydrology, National Weather Service has prepared precipitation frequency analyses for all locations in the United States [14, 15, 16]. Publications are available with generalized charts from which the magnitude of 10-year 24-hour and 25-year 24-hour precipitation amounts can be obtained for any location. Information about the areal variability of rainfall, recurrence intervals, as well as information on evaporation should be requested from that office. Other offices to be contacted for related information include the U. S. Geological Survey, the U. S. Army Corps of Engineers and the U. S. Department of Agriculture's Soil Conservation Service.

SECTION IV

ESTIMATING STORAGE CAPACITY IN COLD REGIONS

If a Soils Treatment System is designed to operate during the winter months in regions where the normal January temperature is colder than about 40°F (4.4°C), storage needs can be estimated by converting days defined as unfavorable into days of storage using either the EPA-1 or EPA-3 program. Temperature, snow depth, and precipitation are examined each day during the months of November through April for a period of 20 to 25 years. The exact period depends on the completeness and length of the digital record for the particular station.

The EPA-1 program [17] defines each day as favorable or unfavorable for operation on the basis of the assigned thresholds. While these thresholds can be varied, almost all stations processed on EPA-1 were assigned thresholds of: mean daily temperature 32°F, 1.00 inch or more of snow cover and 0.50 inch of precipitation as the threshold between favorable and unfavorable days. The maximum storage capacity each winter is estimated by a daily accounting system, where one day's flow is added to storage on days classed as unfavorable, while on favorable days the accumulated storage is reduced by one-half the daily flow. This amount can be changed from station-to-station to match the expected drawdown rate. The maximum storage estimated during each winter season is printed out at the end of the season. A final summary is presented showing the estimated storage days for each of the winter seasons along with percentiles at the .05, .10, .25, and .50 levels. A detailed chronological listing of the daily input can also be furnished that gives one an opportunity to examine the accounting process from day-to-day. Cumulative degree days to base 32°F are also listed. A freezing index is computed for each season and is defined as the difference, in degree days, between the highest and lowest values on a cumulative curve. This index can be considered a measure of the intensity of the cold period as explained in an earlier publication [17]. In the event the system is to be shut down completely during the winter, the duration of the freezing period is usually a better measure of storage needs than the estimate obtained from the favorable-unfavorable day computations.

When a high percentage of the annual precipitation falls in the form of rain or drizzle and the mean daily temperature seldom falls below 32°F (0°C) during the winter months, EPA-1 may not give reasonable estimates of storage. Olympia, Washington is an example of such a station. The problem arises partly from the fact that precipitation can occur almost every day for weeks between the months of November and April. The amounts are often less than 0.50 inch, while at the same time the mean daily temperatures are above 32°F. Although such days are defined as favorable by EPA-1, it is obvious from a review of the daily listings that land application would be undesirable during much of this time because of saturated soil and EPA-2 should be used.

The built-in flexibility of each program is considered one of the principal features since it permits each user to determine the thresholds for his particular situation. One modification to EPA-1 eliminated the snow depth and precipitation constraints entirely. This was done to use the long-term experience at an existing high-rate infiltration system to get an estimate of the temperature threshold for high-rate infiltration systems. If a waste treatment system in a cold region has been operating for many years without being seriously hampered by weather conditions, it follows that similar systems should be able to operate in a similar climate. The mean daily temperature threshold was reduced to a point where the lowest storage estimate at the control station was reduced to a minimum as a best approximation of a reasonable threshold value.

The station selected for this special processing was Lake George, New York, which has operated on a 12-month basis for 40 years despite its relatively cold climate. Spier Falls, New York, about 15 miles to the south, was selected as the weather station with the most suitable climatological record. The temperature threshold was lowered from 32° to 10° F, and each day below this threshold was considered unfavorable. Storage days were estimated using the same daily accounting system as before. These values ranged from 21 days during the most unfavorable season, to one day during the most favorable season.

With this background for the Lake George area, runs were then made using the same 10°F threshold for La Crosse, Wisconsin, and Greenville, Maine, again without regard to snow depth or precipitation. Table 1 gives the results of these runs, along with comparative values based on standard thresholds.

Another modification suggested by Parmalee [18] and Griffes [19] resulted in the development of the EPA-3 program. The proposed changes to EPA-1 included the use of the daily maximum and minimum temperatures instead of the daily mean temperature as the criteria for an unfavorable day. In addition, the daily accounting system was changed slightly and the summary table includes several additional statistics. The storage gain on UNF days is equal to the daily flow (Q). On L days, the gain is equal to the daily flow (Q) minus one-half the assigned drawdown rate, while on FAV days the decrease in storage is equal to the daily flow minus the drawdown rate (DD). The summary table shows the mean number of storage days, the standard deviation of the samples, the unbiased third moment about the mean and the coefficient of skewness. Finally, storage days are computed using the Pearson Type III method. Detailed information about the EPA-3 program can be found in Appendix A.

Program: P03B75–NCC–EPA–1 (Modified)

	Spier Falls, N. Y.			Greenville, Maine			La Crosse, Wis.		
	Mean Jan. Temp. 20.4 F			Mean Jan. Temp. 12.5 F			Mean Jan. Temp. 16.1 F		
	(a)	YEAR	(b)	(a)	YEAR	(b)	(a)	YEAR	(b)
	21.0	1969	132.5	25.0	1970	164.5	13.5	1964	123.5
	14.0	1962	121.5	30.0	1958	149.5	18.5	1950	133.5
	18.0	1960	107.0	29.5	1971	172.0	19.0	1958	123.0
	10.0	1967	108.5	20.0	1964	152.0	20.5	1970	119.5
	8.5	1970	137.0	30.5	1960	152.0	20.0	1962	98.0
	3.0	1958	125.0	20.5	1962	158.0	8.0	1955	133.0
	9.5	1963	116.0	30.5	1967	122.0	7.5	1949	113.5
	7.0	1961	110.5	13.5	1968	176.0	12.5	1961	119.0
	8.0	1964	107.5	13.5	1955	160.5	15.0	1971	120.5
	3.0	1968	131.5	24.0	1961	146.5	12.5	1968	109.5
	5.0	1966	104.5	10.5	1949	147.0	15.0	1969	108.5
	2.5	1971	138.5	12.0	1966	153.5	13.0	1948	104.0
	4.0	1955	130.0	15.5	1963	145.5	12.0	1951	119.0
	4.5	1965	96.0	18.0	1969	150.0	6.0	1966	107.0
	6.0	1954	92.5	18.5	1956	139.0	11.5	1956	98.0
	3.0	1959	114.5	12.5	1951	156.5	8.0	1954	112.5
	5.5	1956	93.5	13.0	1954	146.0	5.0	1959	115.5
	3.5	1951	129.5	6.5	1965	164.5	17.0	1965	80.0
	3.5	1958	104.5	8.5	1959	157.5	12.0	1972	97.0
	4.5	1953	73.0	15.5	1953	136.0	3.0	1952	111.5
	2.0	1950	97.5	6.0	1950	132.5	7.5	1957	95.5
	1.0	1952	73.0	7.0	1952	131.5	13.0	1963	90.0
				9.0	1957	152.5	10.0	1960	70.0
							7.0	1953	84.5
							11.0	1967	76.0
Max	21		139	31		176	21		134
10%	17		135	30		169	19		127

Table 1 Estimated annual storage days based on

(a) mean daily temperature ≤ 10° F, and

(b) standard thresholds of ≤ 32° F, snow depth ≥ 1.00 inch and precipitation ≥ 0.50 inch

SECTION V

ESTIMATING STORAGE CAPACITY IN WET REGIONS

The principal climatic constraint to land application at locations along the Gulf States and the Pacific Northwest Coastal Region is prolonged wet spells, rather than cold or snow. Program EPA-2 examines daily climatological data during a 20 to 25 year period in an attempt to identify days when the soil is saturated. If land application is undesirable during periods when surface runoff could occur, the longest consecutive period defined as "wet" would be an estimation of storage needs. Palmer [2] developed a program that examines weekly (and monthly) temperature and precipitation in order to estimate the duration and magnitude of abnormal moisture deficiency. His analysis yields successive index values on weekly (or monthly) periods for State Climatic Divisions and is currently used to identify meteorological drought.

In the original program, positive index values indicate that the moisture supply from current or antecedent rainfall exceeded the amount required to sustain the evapotranspiration, runoff and moisture storage which could be considered as normal and appropriate for the climate of the area. High positive values mean that fields are too wet to work, or that rains have actually caused flooding. Rains in excess of the estimated water use produce positive values of recharge until the soils reach field capacity. Excess water then shows up as runoff. His classification system is given in Table 2.

TABLE 2

Drought Classification by Palmer

Index	Degree
≥ 4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
.50 to .99	Incipient wet spell
.49 to -.49	Near normal
-.50 to -.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
≤ -4.00	Extreme drought

The underlying concept of Palmer's work is that the amount of precipitation required for the near-normal operation of the agricultural economy of an area during some stated period is dependent on the average climate of the area and on the prevailing meteorological conditions, both during and preceding the period in question. Although his goal was to identify droughts, he found it necessary to identify the entire range of conditions from dry to wet, as shown above. His program appears to work well in identifying droughts and thus became an obvious choice in an attempt to identify prolonged wet spells.

A soil's ability to hold water is dependent upon the thickness of its various horizons, its texture, bulk density, percentage of coarse fragments and the organic content in the profile. The available water capacity (AWC) is commonly defined as the amount of water available to plant roots from the surface to bedrock, or to the unconsolidated non-conforming material such as sand or gravel, or to an arbitrary depth in the case of deep soils [13].

The effect of changing the AWC in the EPA-2 program does not change the number of storage days significantly. This apparently is caused by several factors, perhaps the most obvious is that when wet spells occur, the rainfall is more than sufficient to saturate the soil regardless of its assigned AWC. The surface layer of the soil is assumed to be roughly equivalent to the plow layer. At field capacity it is expected to hold one inch of the available moisture. This is the layer onto which the rain falls and from which evaporation takes place. Therefore, in the moisture accounting it is assumed that evapotranspiration takes place at the potential rate from this surface layer until all the available moisture in the layer has been removed. Only then can moisture be removed from the underlying layer of soil. Likewise, it is assumed that there is no recharge to the underlying portion of the root zone until the surface layer has been brought to field capacity. The available capacity of the soil in the lower layer depends on the depth of the effective root zone and on the soil characteristics in the area under study. It is further assumed that the loss from the underlying layer depends on initial moisture content as well as on the computed potential evapotranspiration (PE) and the available water capacity (AWC) of the soil system.

The distribution of the estimated annual storage days for 25 years from EPA-2 may be a good indicator of how the program is working. One knows from experience that soils are neither always wet nor always dry.

Furthermore, the occurrence of extremely long wet periods is a rarity in most places. The summary of the annual values for 25 years should reveal an almost predictable distribution in terms of range and maximum values. To be more explicit, a large number of years with no storage days, or of estimates over 100 days due to saturated soil, would be suspect almost everywhere except deserts and swamps.

Palmer's original program dealt specifically with weekly and monthly time periods and although he considered the antecedent conditions, it was not necessary for him to be concerned with the amount of runoff. In the daily accounting, the assigned depletion rate serves to approximate the actual drying rate of the soil. It is essential to the program, but it can be changed to suit different conditions. This artificial method of gradually reducing the excess daily runoff is simply a means of accounting for the long-term effect of extremely heavy rainfall. It is a way of describing the continuing restrictive factors ot daily amounts over and above that which would just cause saturation. The program defines a day as unfavorable whenever the amount of moisture in the surface soil (SS), plus that in the underlying soil (SU) and the accumulated daily runoff depleted by a constant (SRO) is equal to or greater than the assigned AWC.

About 75 stations have been processed on the original EPA-2 program that defines a day with runoff as unfavorable. Examination of the daily listings for a number of stations revealed some interesting conditions. Days following those with runoff frequently showed a moisture content in the surface layer very close to saturation. Since the surface layer had not dried out enough to accept the intended amount of application, these days should also be classed as unfavorable and the string of storage days continued. The program was modified to check the amount of moisture in the surface (SS) layer as well as the runoff and to class either condition as unfavorable. The amount of moisture in the surface layer at saturation is always 1.00 inch, with the remainder of the AWC assigned to the underlying layer (SU). Thus, if one selects 0.10 inch as the daily application rate it may be necessary to consider days with SS equal to or greater than 0.90 inch as unfavorable along with those when saturation is indicated. When this feature is used, the program indicator is followed by the percent of SS being considered. For example, in the case stated above, the indicator would be EPA-2(10%); if the application rate was 0.20 inch, the indicator would be EPA-2(20%), etc. This simply says the amount of moisture needed before the surface layer is saturated is the difference between the amount of moisture in that layer and 1.00 inch. This feature may also be useful to planners in estimating irrigation requirements in some areas. Additional changes would have to be made to include a check on the amount of moisture in both SS and SU. The general concept would be to establish minimum moisture needs and then analyze the daily data in terms of the frequency, duration and even total moisture deficit by months, or other time periods.

Examination of the daily listings from EPA-2 shows that most of the wet periods occur during the winter months when evapotranspiration is lowest. The heavy rains of summer do not often result in significant wet spells for a number of reasons. The soil is more likely to be at less than capacity and therefore, in need of recharge. Also, evapotranspiration rates are highest during the growing season. Detailed information about the EPA-2 program is given in Appendix A.

SECTION VI

DISCUSSION

Daily weather reports from the principal observing stations usually include measurements of a number of elements, such as temperature, precipitation, snowfall, snow depth, winds, relative humidity, sunshine, sky cover, etc. These observations have been reported regularly from a network of about 300 stations in the United States for many years, but have been placed on magnetic tape only since about 1948. This network is staffed by meteorologists and most of the stations are located at airports.

Another important source of weather reports is the cooperative network of approximately 10,000 to 12,000 stations. These stations are operated by dedicated volunteers from all walks of life who are making a significant contribution to climatology. Daily reports from this network generally consist of temperature, precipitation, snowfall, snow depth and remarks about unusual weather events. Some networks report only precipitation and river stages, while others include soil temperature and soil moisture measurements. State universities and other interested organizations have made a special effort to place these climatological observations on magnetic tape prior to 1948. Several hundred stations now have digitized record as far back as 1895, or earlier.

In general, observing networks have been established primarily to provide specific weather information to a particular segment of the economy. Some are multi-purpose, of course, and most overlap to some degree. Aviation, hydrology and agriculture are a few examples that need unique and different measurements of the environment. Weather forecasting probably has the broadest base of all in its use of weather observations on a current, or real-time basis. The operational use of weather data is only part of the total picture. Most weather records forwarded to the NCC are edited, sorted and placed in magnetic tape files for future processing. While statistical analysis of climatological data can be very useful, it also has limitations.

One of the first steps in applying climatological data to a specific problem is to insure the presence of an adequate base in digital form (magnetic tape). Consideration should be given to the quality, completeness and length of record, as well as having a large number of stations well distributed throughout the country. The tape decks meeting the above criteria at the NCC are TD-30 and TD-486.

Inventories should be reviewed for completeness before the data can be processed by the programs discussed in this report. If the requested record is inadequate, a substitute station must be used, since a significant number of missing elements or days can bias the results. This means that climatological data from stations 50 to 75 miles from the proposed site may sometimes be used. While each program furnishes selected information about weather conditions at a station during the past quarter of a century, the lack of refinement is obvious. Thresholds to be assigned should be determined by specialists on the site since numerous factors complicate the relationship between rainfall, temperature and wet periods.

Although there is reason to believe that the output from these programs can provide realistic estimates of storage requirements, the limitations are so great in some areas that any measure of confidence may be misleading. At best, these programs offer a simple approximation of storage based on the examination of a few elements. Palmer, and others, developed the basic computer program that provides a realistic picture of moisture excesses and deficiencies many years ago. As more complete and longer records become available, more refined methods of estimating storage will be developed. Future studies will undoubtedly include such elements as solar radiation, wind, moisture and temperature measurements at selected levels above and below the ground, evaporation, precipitation, and others. The present practice at some observing sites of recording certain weather elements only during the growing season should be expanded to include all months. In any case, it is hoped that some of the material presented in this report will stimulate others to examine the data base and respond with improved methods and techniques for estimating storage days.

Finally, daily observations from the cooperative stations reflect weather conditions that existed during the previous 24-hour period. These periods do not coincide with calendar days, since most cooperative observers take their observations in the morning (7 a.m.), or in the evening (5 p.m.). It is entirely possible for one or more of the reported values to have occurred on the previous day. Since there is no real solution to this dilemma, except by having all stations report on a midnight-to-midnight basis, it is the practice in most climatological data processing programs to ignore differences in the hours of observation. For example, it is impossible to tell from the digital records, or indeed, even from some of the original records from the 7 a.m. and 5 p.m. reporting stations, on which date the reported rain actually fell.

SECTION VII

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APPENDIX A

THE COMPUTER PROGRAMS

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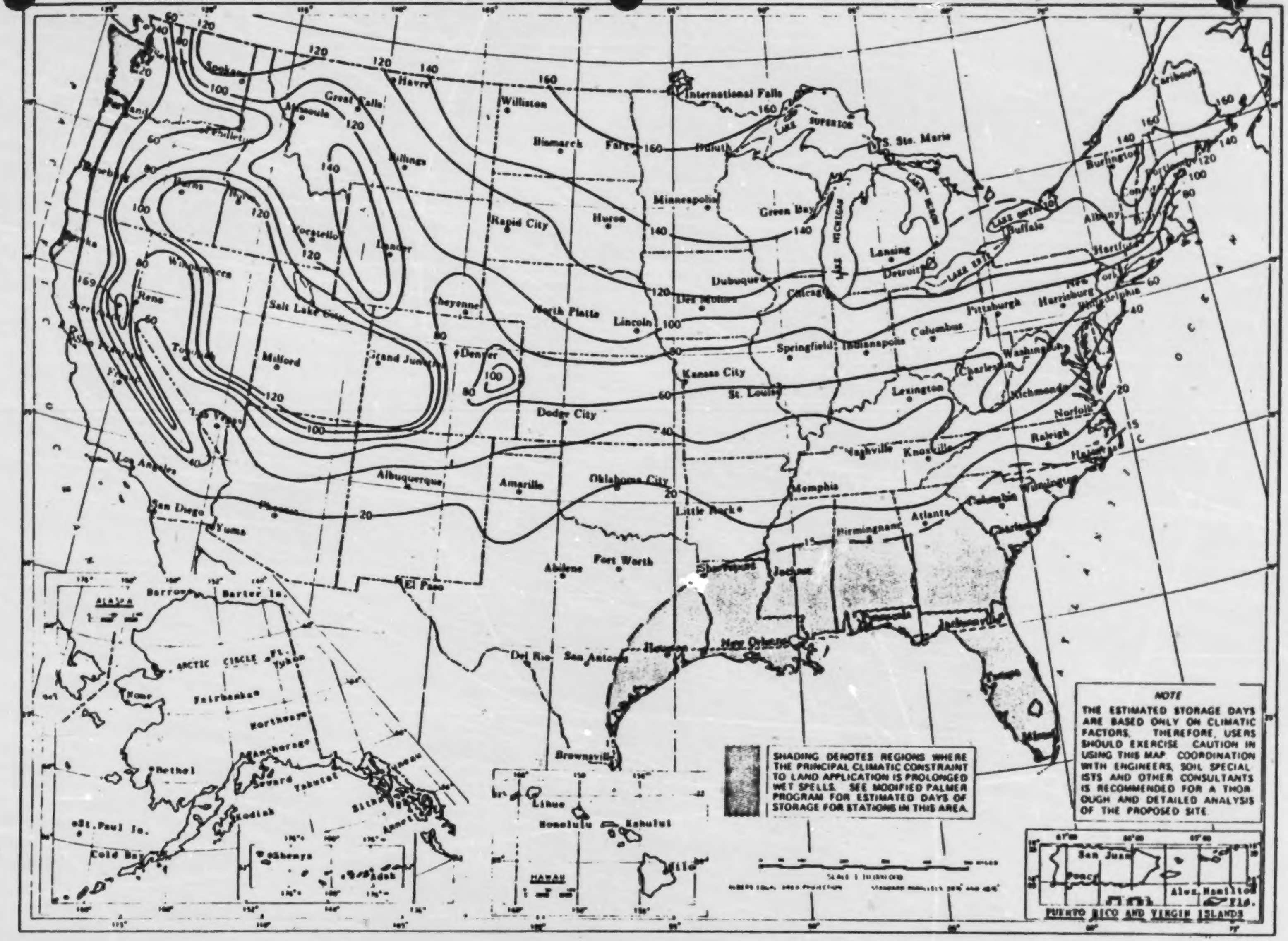

International Falls
Williston
Bismarck
Fargo
Duluth
Sault Ste. Marie
Minneapolis
Green Bay
Rapid City
Huron
Lansing
Detroit
Buffalo
Albany
Burlington
Caribou
Portland
Concord
Hartford
New York
Philadelphia
Harrisburg
Pittsburgh
Dubuque
Chicago
Des Moines
North Platte
Lincoln
Cheyenne
Denver
Springfield
Indianapolis
Columbus
Washington
Charleston
Kansas City
St. Louis
Lexington
Richmond
Norfolk
Raleigh
Dodge City
Nashville
Knoxville
Oklahoma City
Amarillo
Albuquerque
Memphis
Little Rock
Atlanta
Birmingham
Columbia
Wilmington
Abilene
Fort Worth
Shreveport
Jackson
El Paso
Del Rio
San Antonio
Houston
New Orleans
Jacksonville
Brownsville
Miami
Spokane
Great Falls
Havre
Missoula
Billings
Burns
Boise
Pocatello
Lander
Winnemucca
Reno
Salt Lake City
Grand Junction
Milford
Tonopah
Fresno
Las Vegas
Los Angeles
San Diego
Yuma
Phoenix
Seattle
Eureka
Medford
Red Bluff
Sacramento
Lake Superior
Lake Michigan
Lake Huron
Lake Erie
Lake Ontario
160
140
120
100
80
60
40
20
15
ALASKA
Barrow
Barter Is.
Arctic Circle
Ft. Yukon
Nome
Fairbanks
Northway
Anchorage
Bethel
Seward
Yakutat
Sitka
Juneau
Annette
Kodiak
St. Paul Is.
Cold Bay
Wake Island
Adak
HAWAII
Lihue
Honolulu
Kahului
Hilo
San Juan
Ponce
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS
SCALE 1:10,000,000
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29½° AND 45½°

▨ SHADING DENOTES REGIONS WHERE THE PRINCIPAL CLIMATIC CONSTRAINT TO LAND APPLICATION IS PROLONGED WET SPELLS. SEE MODIFIED PALMER PROGRAM FOR ESTIMATED DAYS OF STORAGE FOR STATIONS IN THIS AREA.

NOTE

THE ESTIMATED STORAGE DAYS ARE BASED ONLY ON CLIMATIC FACTORS. THEREFORE, USERS SHOULD EXERCISE CAUTION IN USING THIS MAP. COORDINATION WITH ENGINEERS, SOIL SPECIALISTS AND OTHER CONSULTANTS IS RECOMMENDED FOR A THOROUGH AND DETAILED ANALYSIS OF THE PROPOSED SITE.

Fig. 1 Estimated maximum annual storage days from EPA–1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32° F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
BIRMINGHAM, AL	008	012	0061	013	015	44.2	241	24
MADISON, AL	018	019	0075	020	021	41.2	215	22
MOBILE, AL	004	005	0019	004	006	51.2	298	20
MUSCLE SHOALS, AL	014	018	0089	016	021	41.3	230	25
ONEONTA, AL	012	017	0085	014	020	41.9	219	24
ST. BERNARD, AL	016	018	0100	020	021	40.9	204	20
SCOTTSBORO, AL	012	016	0095	017	020	41.1	210	25
SELMA, AL	004	005	0037	004	006	49.1	262	23
THOMASVILLE, AL	006	008	0041	007	009	47.4	242	20
ASH FORK, AZ	025	024	0115	045	040	36.8	155	22
GANADO, AZ	110	074	0633	114	078	27.5	129	21
CORNING, AR	023	022	0150	024	022	37.7	207	20
DUMAS, AR	011	013	0075	014	021	43.7	223	22
FAYETTEVILLE, AR	029	018	0145	033	031	37.1	181	27
GILBERT, AR	021	020	0154	025	023	37.3	179	20
LITTLE ROCK, AR	018	016	0091	020	019	39.5	238	25
NASHVILLE EXP STN, AR	014	012	0087	017	015	41.9	219	23
NEWPORT, AR	020	016	0094	023	022	40.2	215	21
WALDRON, AR	016	012	0080	017	013	40.8	199	25
CEDARVILLE, CA	066	071	0437	075	072	29.6	131	20
LOS ANGELES, CA	001	004	0001	001	004	54.5	350	25
SALINAS,CA	001	004	0001	001	004	50.0	262	20
SAN FRANCISCO, CA	001	005	0001	001	007	48.3	350	25
SANTA CRUZ,CA	001	006	0001	001	007	48.9	279	24
SUSANVILLE, CA	060	059	0418	068	061	29.9	121	22
TAHOE CITY, CA	123	164	0758	130	169	28.2	075	22
BOULDER, CO	052	049	0346	056	058	33.0	148	24
DENVER, CO	082	056	0563	100	065	29.9	150	24
DURANGO, CO	110	099	0642	112	116	25.9	106	22
FORT COLLINS, CO	105	067	0587	122	071	26.8	140	23
LAMAR, CO	065	046	0531	069	053	29.3	160	22
STRATTON, CO	088	066	0571	094	102	29.7	153	23
TRINIDAD, CO	065	047	0450	093	065	31.0	156	22
BRIDGEPORT, CT	083	064	0410	084	068	30.2	135	23
WILMINGTON, DE	062	053	0312	081	061	32.0	191	25
APALACHICOLA, FL	001	003	0006	002	003	53.7	322	24
AVON PARK, FL	001	002	0001	001	005	62.9	344	27
DAYTONA BEACH, FL	001	003	0001	001	005	58.4	326	17
FT. MYERS, FL	001	003	0001	001	005	63.5	365	24
HOMESTEAD, FL	001	003	0001	001	006	65.3	344	24
JACKSONVILLE, FL	002	003	0006	003	004	54.6	313	19
TAMPA, FL	001	004	0001	001	005	60.4	349	21
WEST PALM BEACH, FL	001	004	0001	001	004	65.5	365	21

Table 3 Selected information for stations, EPA—1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32° F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
ATHENS, GA	008	010	0044	010	016	44.5	221	24
AUGUSTA, GA	004	005	0026	005	007	45.8	219	23
ATLANTA, GA	012	011	0055	014	016	42.4	236	24
BLAIRSVILLE EXP STA,GA	035	031	0154	053	048	37.8	172	25
MACON, GA	004	005	0030	004	007	47.8	240	23
BOISE, ID	085	077	0476	094	087	29.0	159	24
CAMBRIDGE, ID	115	101	1256	122	120	22.5	117	24
LEWISTON, ID	050	048	0505	063	059	31.2	179	25
POCATELLO, ID	116	109	1252	125	125	23.2	142	25
CAIRO,IL	022	028	0179	035	034	36.3	230	25
CHICAGO,IL/MIDWAY	093	081	0954	129	086	24.3	192	25
HOOPESTON,IL	095	072	0746	119	076	26.2	170	25
MOLINE,IL	110	092	1106	135	095	21.5	174	25
MT.VERNON,IL	076	042	0342	080	046	32.1	191	24
PANA,IL	076	061	0519	086	065	28.9	186	25
PEORIA,IL	095	083	0906	129	088	23.8	181	25
BERNE, IN	089	074	0661	101	086	27.1	160	25
COLUMBUS, IN	077	061	0472	087	062	30.1	167	25
CRAWFORDSVILLE, IN	090	073	0714	101	086	27.2	163	25
EVANSVILLE, IN	060	045	0343	084	049	32.6	216	25
SOUTH BEND, IN	104	101	0926	132	109	24.0	165	25
BELLE PLAINE, IA	128	113	1387	135	126	19.8	155	25
DES MOINES, IA	128	106	1416	136	111	19.4	175	25
HAMPTON, IA	140	126	1788	146	136	16.3	144	23
KEOSAUQUA, IA	091	084	0875	119	090	24.4	168	27
LOGAN, IA	114	105	1152	128	107	20.6	162	25
SHENANDOAH, IA	101	077	0822	119	095	23.8	167	25
DODGE CITY, KS	066	048	0381	094	053	30.8	184	23
GOODLAND, KS	093	066	0614	121	073	27.6	157	23
HAYS, KS	090	064	0593	129	065	27.8	167	23
HEALY, KS	073	062	0463	094	067	29.9	164	23
HERINGTON, KS	084	052	0445	092	064	29.1	185	23
INDEPENDENCE, KS	034	026	0224	041	032	33.9	196	23
JUNCTION CITY, KS	059	049	0396	069	058	28.7	175	23
BOWLING GREEN, KY	032	039	0217	036	040	35.6	204	25
LEXINGTON, KY	073	048	0310	084	052	32.9	198	25
PADUCAH, KY	041	037	0228	047	038	36.0	209	25
ARCADIA, LA	007	012	0060	009	012	45.6	246	22
LAFAYETTE, LA	003	004	0015	004	005	51.9	275	25
LAKE PROVIDENCE, LA	007	012	0061	011	016	46.0	252	25
LEESVILLE, LA	004	005	0036	005	006	49.7	243	21
MONROE, LA	006	009	0051	006	010	46.7	253	25
SHREVEPORT, LA	005	006	0047	006	009	47.2	272	25
WINNFIELD, LA	005	006	0043	005	008	48.4	240	21

Table 3 Selected information for stations, EPA–1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32°F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
BAR HARBOR, ME	111	128	0976	120	140	23.7	156	23
EASTPORT, ME	124	122	1012	127	130	22.6	174	23
GREENVILLE, ME	158	169	2268	159	172	12.5	110	23
BALTIMORE, MD	028	053	0183	033	055	36.1	200	22
ADAMS, MA	126	117	1266	132	123	21.0	127	25
BOSTON, MA	084	080	0418	089	081	29.2	217	25
HAVERHILL, MA	094	102	0640	112	104	26.8	181	25
WORCESTER, MA	122	118	0953	133	126	23.6	148	25
MUSKEGON, MI	124	116	1040	127	119	24.0	161	23
INTERNATIONAL FALLS,MN	161	168	3506	164	172	01.9	095	23
MINNEAPOLIS, MN	141	143	2174	146	143	12.2	166	23
PARK RAPIDS, MN	159	155	3186	164	159	05.0	122	24
ABERDEEN, MS	008	011	0051	013	013	44.7	228	24
CLARKSDALE, MS	017	016	0083	020	021	43.1	236	25
COLUMBIA, MS	003	006	0020	004	009	50.4	239	24
MERIDIAN, MS	006	008	0033	011	015	46.9	246	24
PONTOTOC, MS	010	014	0077	013	019	43.2	223	24
STONEVILLE EXP STA, MS	011	013	0077	012	017	44.2	229	23
ST. LOUIS, MO	075	044	0367	085	051	31.3	206	25
SALISBURY, MO	082	054	0470	090	071	27.8	186	25
SPRINGFIELD, MO	040	039	0274	047	043	32.9	201	25
TARKIO, MO	098	084	0869	119	090	24.0	170	22
WARSAW, MO	043	037	0296	050	038	32.5	185	23
WEST PLAINS, MO	038	033	0232	040	035	33.8	178	25
BILLINGS, MT	128	100	1342	139	102	21.9	132	25
BOZEMAN, MT	134	144	1348	137	152	20.8	107	23
DILLON, MT	138	128	1647	139	132	20.2	099	25
GREAT FALLS, MT	128	091	1557	132	102	20.5	135	25
MILES CITY, MT	134	123	2356	138	140	15.4	150	25
MISSOULA, MT	133	121	1309	137	128	20.8	095	25
GRAND ISLAND, NE	121	098	1173	132	103	22.3	151	25
IMPERIAL, NE	093	082	0765	121	092	26.9	150	25
SCOTTSBLUFF, NE	117	075	0804	134	081	24.9	135	25
VALENTINE, NE	128	104	1401	136	119	20.4	146	25
ADAVEN, NV	085	086	0425	096	102	30.6	119	24
ELKO, NV	124	117	1230	125	124	23.2	089	25
ELY, NV	133	120	1362	134	137	23.6	126	25
LOVELOCK, NV	083	061	0459	087	080	28.9	135	25
RENO, NV	058	050	0374	064	067	31.9	141	25

Table 3 Selected information for stations, EPA—1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32°F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
LEBANON, NH	136	135	1569	137	147	18.1	120	25
ATLANTIC CITY, NJ	040	032	0138	045	036	32.7	225	25
NEWARK, NJ	070	054	0302	082	059	31.4	219	25
TRENTON, NJ	064	053	0280	083	056	32.1	218	25
ALBUQUERQUE, NM	034	024	0159	057	026	35.2	196	24
ARTESIA,NM	013	013	0160	013	013	40.8	220	21
CIMARRON, NM	074	034	0296	099	074	32.2	150	25
CLAYTON, NM	049	035	0235	056	042	33.1	166	25
CLOVIS, NM	018	015	0149	018	020	37.2	198	22
SANTA FE,NM	095	065	0493	095	065	29.8	165	17
BUFFALO, NY	119	103	0948	126	108	23.7	179	25
ELMIRA, NY	120	104	1021	125	113	25.0	156	25
POUGHKEEPSIE, NY	089	086	0760	108	092	26.5	177	25
ROCHESTER, NY	124	115	0970	125	121	24.0	176	23
SPIER FALLS, NY	125	135	1405	138	139	20.4	150	23
SYRACUSE, NY	117	115	0975	125	118	23.6	168	25
WATERTOWN, NY	127	126	1467	132	128	18.8	151	25
CANTON, NC	023	035	0171	052	041	38.0	195	25
CHARLOTTE, NC	010	011	0052	010	014	42.1	239	25
ELIZABETH CITY, NC	010	013	0036	011	016	42.3	226	25
FAYETTEVILLE, NC	008	010	0045	013	012	43.0	222	25
GREENSBORO, NC	016	024	0086	023	030	38.7	211	25
HICKORY, NC	013	020	0070	020	025	39.1	210	24
LAURINBURG, NC	006	008	0028	009	012	43.9	212	25
MAYSVILLE, NC	009	011	0040	013	012	45.0	241	23
RALEIGH, NC	013	017	0061	021	021	40.5	237	25
SALISBURY, NC	010	014	0061	016	015	40.9	205	25
WELDON, NC	015	017	0082	021	029	40.5	193	23
WILMINGTON, NC	004	007	0023	006	007	46.4	262	25
WILSON, NC	008	011	0044	011	015	42.5	222	24
BISMARCK, ND	146	140	3103	148	144	08.2	136	24
DEVILS LAKE, ND	158	156	3533	165	168	04.2	127	24
WILLISTON, ND	144	141	2975	147	146	08.3	132	24
AKRON CANTON, OH	103	087	0761	109	092	26.3	173	25
COLUMBUS, OH	084	071	0578	087	076	28.4	196	25
DAYTON, OH	084	069	0599	092	071	28.1	165	25
FINDLAY, OH	106	088	0772	130	095	25.8	160	25
ADA, OK	017	013	0085	020	014	40.9	220	22
BARTLESVILLE, OK	022	020	0170	025	020	35.4	210	23
HOBART, OK	020	018	0169	026	020	37.3	210	23
MADILL, OK	013	010	0069	018	012	42.1	227	23
OKLAHOMA CITY, OK	022	018	0166	026	020	36.8	223	22
PAULS VALLEY, OK	013	014	0091	016	016	39.7	207	23
POTEAU, OK	016	012	0082	018	014	41.1	212	23

Table 3 Selected information for stations, EPA-1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32°F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
BURNS, OR	108	102	0774	122	119	25.2	111	25
EUGENE, OR	010	026	0119	027	032	39.4	199	25
KLAMATH FALLS, OR	087	089	0400	103	091	29.7	126	25
MEDFORD, OR	018	020	0085	025	022	36.6	184	25
PENDLETON, OR	037	042	0526	062	052	32.0	196	25
PORTLAND, OR	014	027	0094	023	037	38.1	211	25
REDMOND, OR	044	049	0379	075	071	30.2	075	23
ROSEBURG, OR	006	010	0056	008	015	40.9	219	28
SALEM, OR	012	023	0101	028	029	38.8	192	25
ERIE, PA	113	098	0741	114	109	25.1	200	23
PHILADEPHIA, PA	068	057	0322	083	064	32.3	190	25
PITTSBURGH, PA	069	049	0421	085	053	28.1	187	25
STATE COLLEGE, PA	104	094	0709	113	106	27.0	166	25
WILLIAMSPORT, PA	093	088	0726	098	095	27.2	164	25
PROVIDENCE, RI	089	076	0526	090	080	28.4	197	24
CHARLESTON, SC	003	004	0018	004	006	48.6	294	24
COLUMBIA, SC	005	006	0025	005	007	45.4	252	25
CONWAY, SC	004	006	0024	005	008	46.5	240	26
FLORENCE, SC	005	008	0024	006	009	45.6	241	25
RAINBOW LAKE, SC	007	012	0041	009	012	42.1	210	25
SUMMERVILLE, SC	004	005	0021	004	006	47.4	252	25
ABERDEEN, SD	145	138	2690	148	142	09.5	137	25
BROOKINGS, SD	144	131	2365	147	136	12.0	137	24
PIERRE, SD	136	126	2205	142	136	15.6	155	25
RAPID CITY, SD	128	099	1291	136	100	21.9	150	25
CHATTANOOGA, TN	012	020	0097	020	022	40.2	229	25
CROSSVILLE, TN	054	052	0322	085	055	34.5	176	20
KINGSPORT, TN	022	024	0146	022	028	36.4	190	27
KNOXVILLE, TN	021	022	0125	035	031	40.6	220	25
MEMPHIS, TN	019	017	0108	022	025	40.5	237	25
NASHVILLE, TN	022	028	0150	032	031	38.3	224	25
AMARILLO, TX	021	023	0205	031	027	36.0	191	25
CORPUS CHRISTI, TX	001	003	0003	003	005	56.3	306	21
DALHART, TX	038	027	0195	051	032	33.8	185	24
DALLAS, TX	005	008	0052	007	010	45.4	239	25
EL PASO, TX	005	005	0048	006	006	43.6	243	24
LUBBOCK, TX	016	014	0118	018	020	39.1	204	24
LUFKIN, TX	004	005	0034	006	006	48.8	231	24
MIDLAND, TX	006	007	0058	007	010	43.6	232	24
WICHITA FALLS, TX	016	015	0090	018	017	41.5	216	24
BLANDING, UT	098	091	0623	109	110	27.7	148	25
HANKSVILLE, UT	082	073	0934	090	089	26.1	156	24
LOGAN, UT	130	109	0931	131	113	24.0	165	21
MILFORD, UT	112	090	1007	129	101	25.7	128	25
NEPHI, UT	092	075	0675	109	089	26.0	137	23
SALT LAKE CITY, UT	098	089	0765	107	115	28.0	202	25

Table 3 Selected information for stations, EPA—1 program

STATION	LENGTH OF FREEZE PERIOD (10 %)	ESTIMATED STORAGE DAYS (10 %)	FREEZE INDEX (10 %) (BASE 32° F)	LENGTH OF MAXIMUM FREEZE PERIOD (DAYS)	ESTIMATED MAXIMUM STORAGE DAYS	NORMAL JANUARY TEMPERATURE	GROWING SEASON (DAYS)	YEARS
BURLINGTON, VT	138	134	1800	143	136	16.8	148	25
BLACKSTONE, VA	016	025	0100	026	031	38.3	181	24
HOT SPRINGS, VA	080	066	0338	101	067	31.6	135	22
NORFOLK, VA	013	015	0059	017	022	40.5	219	25
WASHINGTON,DC/NATIONAL	039	034	0122	062	047	35.6	200	25
LONGVIEW, WA	021	029	0104	028	049	38.2	182	24
OLYMPIA,WA	034	035	0227	034	045	37.2	344	23
SEATTLE, WA	022	033	0081	034	036	38.2	233	25
SPOKANE, WA	105	100	0953	124	106	25.4	169	25
SUNNYSIDE, WA	058	050	0536	102	059	30.5	158	25
VANCOUVER, WA	028	028	0192	033	034	38.4	233	23
WALLA WALLA, WA	036	042	0476	054	051	33.4	202	25
WENATCHEE, WA	093	087	0849	110	122	26.6	188	22
BLUESTONE DAM, WV	065	052	0322	084	058	31.1	150	25
CHARLESTON, WV	065	044	0272	084	049	34.5	193	25
MORGANTOWN, WV	072	060	0486	085	070	31.5	165	25
ASHLAND, WI	147	148	2353	149	149	12.1	109	22
EAU CLAIRE, WI	144	141	2339	148	147	11.7	151	24
GREEN BAY, WI	140	135	1932	148	139	15.4	161	25
LACROSSE, WI	139	127	1925	146	134	16.1	161	25
MADISON, WI	134	119	1700	146	125	16.8	177	25
RHINELANDER, WI	146	149	2344	147	156	12.3	085	21
WEYERHAUSER, WI	145	145	2289	150	148	11.3	125	21
AFTON, WY	149	144	2163	159	156	14.3	018	25
CASPER, WY	136	095	1140	138	101	23.2	130	25
GILLETTE, WY	134	108	1229	125	113	21.7	129	22
ROCK SPRINGS, WY	145	136	1718	151	142	19.2	060	25
WHEATLAND, WY	099	058	0536	127	066	28.9	102	25

Table 3 Selected information for stations, EPA–1 program

Station	Normal January Temp. (°F)	Normal Annual Precip. (in.)	EPA-1	EPA-2	General Period
Alabama					
Mobile	51	67	6	15	1949-73
Selma	49	52	6	20	1949-73
Thomasville	45	56	9	25	1953-74
Arkansas					
Dumas	44	50	21	19	1951-71
Little Rock	40	49	19	12	1949-72
California					
Los Angeles	55	12	4	5	1952-69
San Francisco	48	20	7	13	1949-72
Florida					
Avon Park	63	55	5	13	1945-72
Daytona Beach	58	50	5	8	1955-73
Tampa	60	49	5	16	1953-73
Georgia					
Augusta	46	43	7	10	1949-72
Macon	48	44	7	12	1949-72
Louisiana					
Lafayette	52	57	5	12	1948-73
Lake Providence	46	53	16	19	1951-72
Leesville	50	54	6	35	1950-73
Monroe	47	50	10	12	1949-72
Shreveport	47	45	9	11	1949-72
Winnfield	48	55	8	16	1950-73
Mississippi					
Aberdeen	45	53	13	24	1951-72
Clarksdale	43	49	21	18	1949-72
Columbia	50	61	9	33	1947-73
Meridian	47	52	15	14	1948-73
Pontotoc	43	55	19	20	1949-71
Stoneville	44	50	17	17	1951-72
North Carolina					
Charlotte	42	42	14	12	1949-73
Raleigh	41	43	21	14	1949-73
Weldon	41	43	29	11	1926-50
Wilmington	46	54	7	11	1949-73
Oregon					
Eugene	39	43	32	35	1948-73
Medford	37	21	22	21	1948-72
Roseburg	41	34	15	22	1935-64
Salem	39	41	29	36	1948-73
South Carolina					
Charleston	49	52	6	24	1948-73
Columbia	45	46	7	15	1949-73
Conway	47	52	8	9	1945-73
Tennessee					
Crossville	35	57	55	24	1953-73
Texas					
Amarillo	36	20	27	11	1949-71
Corpus Christi	56	29	5	13	1951-72
Dallas	45	36	10	15	1948-72
El Paso	44	8	6	0	1948-72
Wichita Falls	42	27	17	8	1950-72
Washington					
Longview	38	46	49	60	1948-73
Olympia	37	51	45	65*	1949-73
Vancouver	38	40	34	31	1924-50
Walla Walla	33	16	51	14	1950-73

* This station shows 145 storage days when processed under EPA-2 (10%)

Fig. 2 Comparison between maximum annual storage days estimated from EPA-1 and EPA-2 programs

LIST OF SYMBOLS

STA: Station
YR: Year (20 to 30 years of record)
MO: Month 01 = January, 02 = February, etc.
DA: 01 – 31
MN: Daily minimum temperature (°F)
MX: Daily maximum temperature (°F)
T: Daily mean temperature (°F)
P: Daily precipitation (inches), Trace = 0.00
SP: Available moisture in the soil at the start of a day. Saturation is assumed when SP = AWC (available water capacity)
SS: Amount of available moisture in the surface soil at the end of a day.
SU: Amount of available moisture in the underlying soil at the end of a day.
PE: Daily potential evapotranspiration (Thornthwaite)
PL: Daily potential moisture loss
PR: Potential recharge; at the start of a day this is the number of inches required to bring the soil to field capacity
R: Daily recharge; net gain in the surface and underlying soil
L: Daily moisture loss from the surface and underlying soil
ET: Daily evapotranspiration
DR: Depletion rate
RO: Daily runoff
ARO: Accumulated runoff. This is the sum of the previous days SRO and the current days runoff; $ARO = SRO' + RO$
SRO: Accumulated daily runoff minus the depletion rate; $SRO = ARO - DR$
AWC: Available water capacity of the soil. At saturation, $AWC = SS + SU$
UNF: "X" denotes an unfavorable day for land application because of possible surface runoff

(If SRO + SS + SU is equal to or greater than the available water capacity, the day is unfavorable)

Note: Symbols with a prime (′) indicate conditions at the start of a day. Subscripts s and u indicate "surface" and "underlying", respectively.

Constants which must be supplied for the station being analyzed are:

I, the heat index
b, a coefficient which depends on the heat index
g, the tangent of the station's latitude
W, the available water capacity of the soil minus 1.0 inch in inches
ϕ, Daily solar declination, in radians

To start the analysis two values must be assigned: SS′, in inches (to hundredths) of soil moisture available in the surface soil at the start, and SU′, in inches (to hundredths) of soil moisture available in the underlying soil at the start.

Fig. 3 Explanation of symbols used in the listings from EPA–2

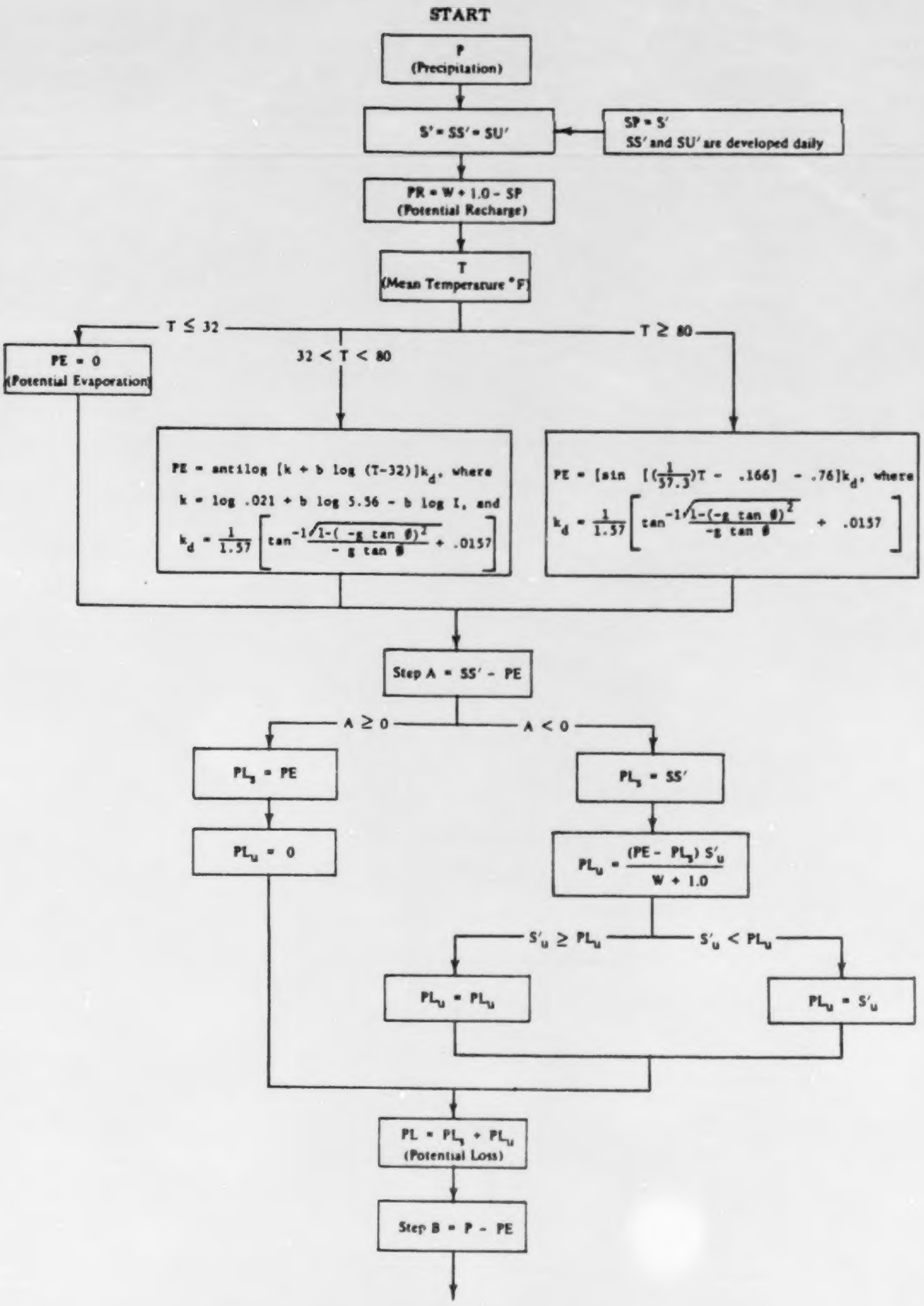

START
P
(Precipitation)
S' = SS' = SU'
SP = S'
SS' and SU' are developed daily
PR = W + 1.0 - SP
(Potential Recharge)
T
(Mean Temperature °F)
T ≤ 32
32 < T < 80
T ≥ 80
PE = 0
(Potential Evaporation)
PE = antilog [k + b log (T-32)]k_d, where
k = log .021 + b log 5.56 - b log I, and
$k_d = \frac{1}{1.57}\left[\tan^{-1}\frac{\sqrt{1-(-g\tan\theta)^2}}{-g\tan\theta} + .0157\right]$
PE = [sin [($\frac{1}{57.3}$)T - .166] - .76]k_d, where
$k_d = \frac{1}{1.57}\left[\tan^{-1}\frac{\sqrt{1-(-g\tan\theta)^2}}{-g\tan\theta} + .0157\right]$
Step A = SS' - PE
A ≥ 0
A < 0
PL_s = PE
PL_u = 0
PL_s = SS'
$PL_u = \frac{(PE - PL_s)\,S'_u}{W + 1.0}$
$S'_u \geq PL_u$
$S'_u < PL_u$
PL_u = PL_u
PL_u = S'_u
PL = PL_s + PL_u
(Potential Loss)
Step B = P - PE

Fig. 4 Flow diagram for the modified Palmer program (EPA—2)

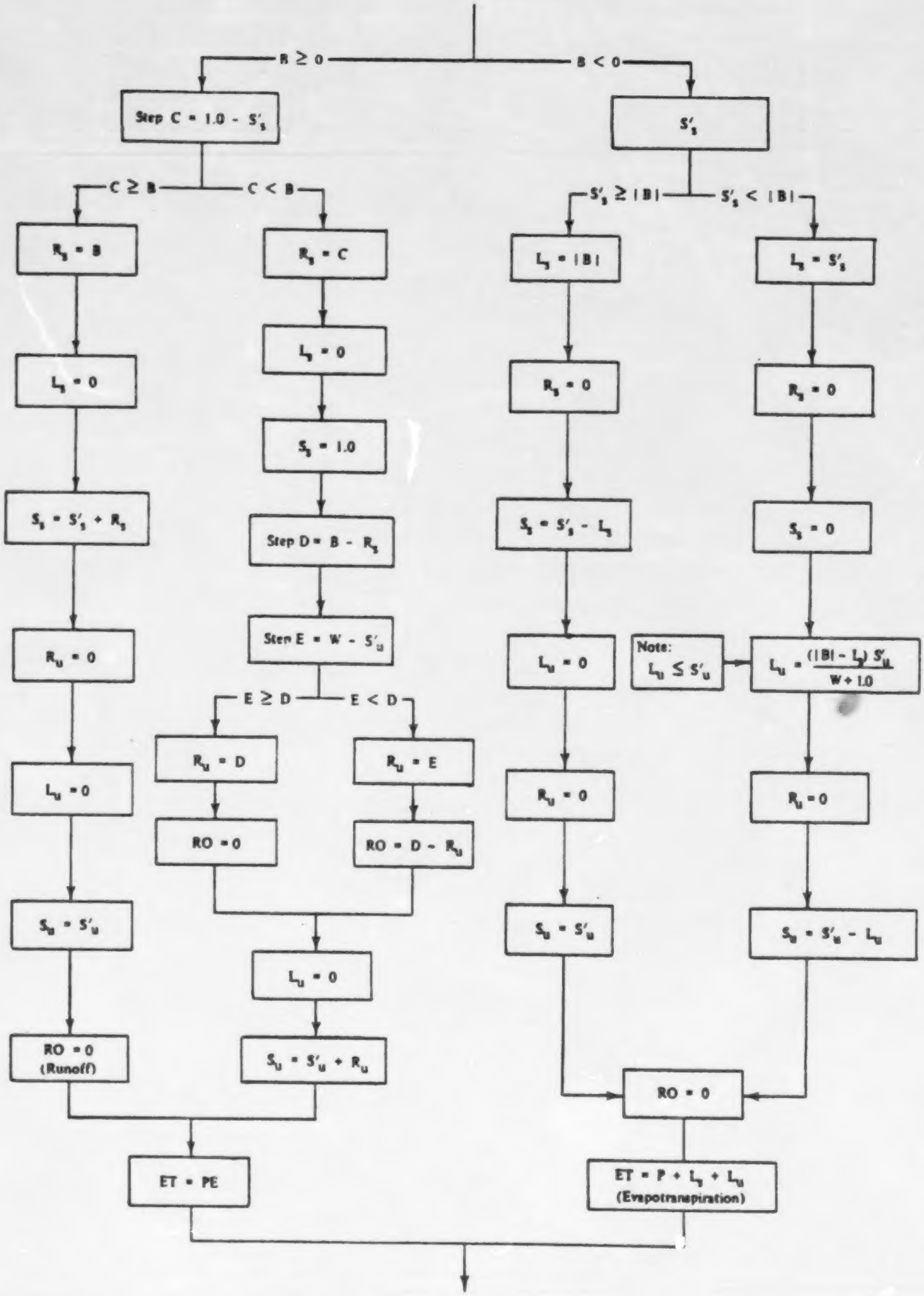
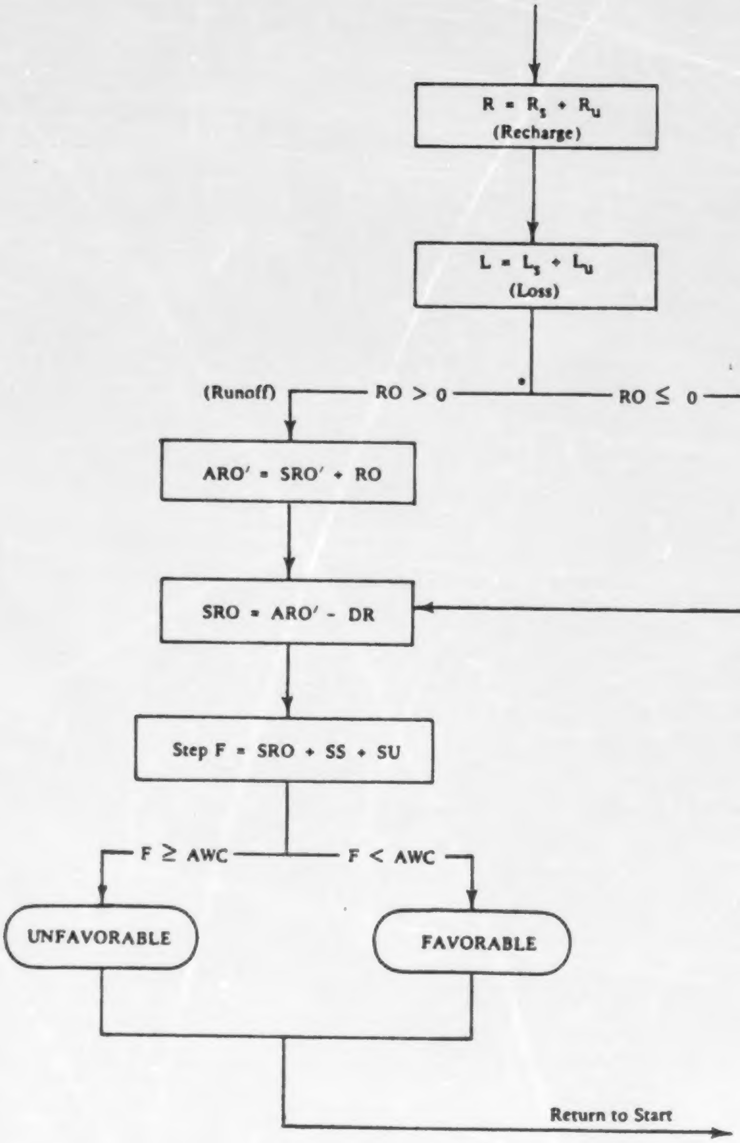

B ≥ 0
B < 0
Step C = 1.0 - S′s
S′s
C ≥ B
C < B
S′s ≥ |B|
S′s < |B|
Rs = B
Rs = C
Ls = |B|
Ls = S′s
Ls = 0
Ls = 0
Rs = 0
Rs = 0
Ss = 1.0
Ss = S′s + Rs
Step D = B - Rs
Ss = S′s - Ls
Ss = 0
Ru = 0
Step E = W - S′u
Lu = 0
Note: Lu ≤ S′u
Lu = (|B| - Ls) S′u / W + 1.0
E ≥ D
E < D
Ru = D
Ru = E
Lu = 0
Ru = 0
Ru = 0
RO = 0
RO = D - Ru
Su = S′u
Su = S′u
Su = S′u - Lu
Lu = 0
RO = 0 (Runoff)
Su = S′u + Ru
RO = 0
ET = PE
ET = P + Ls + Lu (Evapotranspiration)

Fig. 4 Flow diagram for modified Palmer program (EPA–2) cont'd.


R = R_s + R_u
(Recharge)
L = L_s + L_u
(Loss)
*
(Runoff)
RO > 0
RO ≤ 0
ARO′ = SRO′ + RO
SRO = ARO′ - DR
Step F = SRO + SS + SU
F ≥ AWC
F < AWC
UNFAVORABLE
FAVORABLE
Return to Start

[*] The original Palmer program that computes the drought severity indices continues from this point and runs about as long as the portion shown here. Most of the constants for EPA–2 are stored on a separate tape at NCC; however, some values must be extracted from the earlier Palmer tabulations. This means that although there are no restrictions on the use or dissemination of the programs, a considerable amount of time and effort are required to collect the necessary material. In addition, a 20 to 25-year period of record can be processed at the Center for less than the cost of the program. Finally, the daily data must be purchased along with the program for each station of interest.

Fig. 4 Flow diagram for modified Palmer program (EPA–2) cont'd.

```
STATION  DATE MN MX    T      P     SP   SS     SU    PE    PL    PR     R     L    ET    RO   SRO   UNF
223627 58 828 60 89 74.5   0.00   3.07 0.00   2.92  0.15  0.15  2.93  0.00  0.15  0.15  0.00  0.00
223627 58 829 63 90 76.5   0.00   2.92 0.00   2.83  0.17  0.08  3.08  0.00  0.08  0.08  0.00  0.00
223627 58 830 65 90 77.5   0.00   2.83 0.00   2.75  0.17  0.08  3.17  0.00  0.08  0.08  0.00  0.00
223627 58 831 70 94 82.0   0.00   2.75 0.00   2.66  0.21  0.10  3.25  0.00  0.10  0.10  0.00  0.00
223627 58 9 1 71 94 82.5   0.00   2.66 0.00   2.56  0.21  0.09  3.34  0.00  0.09  0.09  0.00  0.00
223627 58 9 2 69 95 82.0   0.00   2.56 0.00   2.47  0.21  0.09  3.44  0.00  0.09  0.09  0.00  0.00
223627 58 9 3 70 93 81.5   0.00   2.47 0.00   2.39  0.20  0.08  3.53  0.00  0.08  0.08  0.00  0.00
223627 58 9 4 70 89 79.5   0.00   2.39 0.00   2.32  0.19  0.07  3.61  0.00  0.07  0.07  0.00  0.00
223627 58 9 5 71 89 78.0   0.00   2.32 0.00   2.25  0.17  0.07  3.68  0.00  0.07  0.07  0.00  0.00
223627 58 9 6 69 93 81.0   0.00   2.25 0.00   2.17  0.20  0.07  3.75  0.00  0.07  0.07  0.00  0.00
223627 58 9 7 70 92 81.0   0.00   2.17 0.00   2.10  0.20  0.07  3.83  0.00  0.07  0.07  0.00  0.00
223627 58 9 8 67 90 78.5   0.00   2.10 0.00   2.04  0.18  0.06  3.90  0.00  0.06  0.06  0.00  0.00
223627 58 9 9 61 89 75.0   0.00   2.04 0.00   1.99  0.15  0.05  3.96  0.00  0.05  0.05  0.00  0.00
223627 58 910 63 92 77.5   0.24   1.99 0.07   1.99  0.17  0.06  4.01  0.07  0.00  0.17  0.00  0.00
223627 58 911 70 79 74.5   1.56   2.06 1.00   2.47  0.15  0.10  3.94  0.07  0.00  0.15  0.00  0.00
223627 58 912 68 79 73.5   0.00   3.47 0.86   2.47  0.14  0.14  2.53  0.00  0.14  0.14  0.00  0.00
223627 58 913 66 79 72.5   0.00   3.33 0.73   2.47  0.13  0.13  2.67  0.00  0.13  0.13  0.00  0.00
223627 58 914 65 84 74.5   0.00   3.20 0.58   2.47  0.15  0.15  2.80  0.00  0.15  0.15  0.00  0.00
223627 58 915 72 88 80.0   0.48   3.05 0.87   2.47  0.19  0.19  2.95  0.29  0.00  0.19  0.00  0.00
223627 58 916 72 90 81.0   1.07   3.34 1.00   3.22  0.19  0.19  2.64  0.29  0.00  0.19  0.00  0.00
223627 58 917 69 79 74.0   0.75   4.22 1.00   3.83  0.14  0.14  1.78  0.29  0.00  0.14  0.00  0.00
223627 58 918 67 79 73.0   0.00   4.83 0.67   3.83  0.13  0.13  1.17  0.00  0.13  0.13  0.00  0.00
223627 58 919 69 83 76.0   2.67   4.49 1.00   5.00  0.15  0.15  1.31  0.00  0.00  0.15  1.21  0.46    X
223627 58 920 72 76 74.0   8.07   6.00 1.00   5.00  0.14  0.14  0.00  0.00  0.00  0.14  7.93  7.64    X
223627 58 921 71 79 75.0   2.48   6.00 1.00   5.00  0.15  0.15  0.00  0.00  0.00  0.15  2.33  9.22    X
223627 58 922 69 84 76.5   0.00   6.00 0.84   5.00  0.16  0.16  0.00  0.00  0.16  0.16  0.00  8.47    X
223627 58 923 70 86 78.0   0.16   5.84 0.84   5.00  0.17  0.17  0.16  0.00  0.01  0.17  0.00  7.72    X
223627 58 924 73 88 80.5   0.00   5.84 0.65   5.00  0.19  0.19  0.16  0.00  0.19  0.19  0.00  6.97    X
223627 58 925 74 92 83.0   0.00   5.65 0.45   5.00  0.20  0.20  0.35  0.00  0.20  0.20  0.00  6.22    X
223627 58 926 73 92 82.5   0.00   5.45 0.25   5.00  0.20  0.20  0.55  0.00  0.20  0.20  0.00  5.47    X
223627 58 927 64 80 72.0   0.00   5.25 0.13   5.00  0.12  0.12  0.75  0.00  0.12  0.12  0.00  4.72    X
223627 58 928 55 75 65.0   0.00   5.13 0.04   5.00  0.09  0.09  0.87  0.00  0.09  0.09  0.00  3.97    X
223627 58 929 51 80 65.5   0.00   5.04 0.00   4.96  0.09  0.08  0.96  0.00  0.08  0.08  0.00  3.22    X
223627 58 930 56 76 66.0   2.17   4.96 1.00   5.00  0.09  0.07  1.04  0.00  0.00  0.09  1.04  3.52    X
223627 5810 1 51 69 60.0   0.32   6.00 1.00   5.00  0.06  0.06  0.00  0.00  0.00  0.06  0.26  3.02    X
223627 5810 2 48 70 59.0   0.00   6.00 0.94   5.00  0.06  0.06  0.00  0.00  0.06  0.06  0.00  2.27    X
223627 5810 3 53 63 58.0   0.12   5.94 1.00   5.00  0.05  0.05  0.06  0.00  0.00  0.05  0.01  1.53    X
223627 5810 4 57 75 66.0   0.00   6.00 0.91   5.00  0.07  0.09  0.00  0.00  0.09  0.09  0.00  0.78    X
223627 5810 5 57 78 67.5   0.00   5.91 0.81   5.00  0.10  0.10  0.09  0.00  0.10  0.10  0.00  0.03     016
223627 5810 6 54 84 69.0   0.00   5.81 0.71   5.00  0.10  0.10  0.19  0.00  0.10  0.10  0.00  0.00
223627 5810 7 60 81 70.5   0.00   5.71 0.60   5.00  0.11  0.11  0.29  0.00  0.11  0.11  0.00  0.00
223627 5810 8 64 84 74.0   0.00   5.60 0.46   5.00  0.13  0.13  0.40  0.00  0.13  0.13  0.00  0.00
223627 5810 9 69 86 77.5   0.06   5.46 0.37   5.00  0.16  0.16  0.56  0.00  0.10  0.16  0.00  0.00
223627 581010 58 76 67.0   0.00   5.37 0.28   5.00  0.09  0.09  0.63  0.00  0.09  0.09  0.00  0.00
223627 581011 53 72 62.5   0.00   5.28 0.21   5.00  0.07  0.07  0.72  0.00  0.07  0.07  0.00  0.00
223627 581012 52 77 64.5   0.00   5.21 0.13   5.00  0.08  0.08  0.79  0.00  0.08  0.08  0.00  0.00
223627 581013 49 81 65.0   0.00   5.13 0.04   5.00  0.08  0.08  0.87  0.00  0.08  0.08  0.00  0.00
223627 581014 51 79 65.0   0.00   5.04 0.00   4.97  0.08  0.08  0.96  0.00  0.08  0.08  0.00  0.00
223627 581015 55 79 67.0   0.00   4.97 0.00   4.89  0.09  0.08  1.03  0.00  0.08  0.08  0.00  0.00
223627 581016 60 80 70.0   0.00   4.89 0.00   4.81  0.11  0.09  1.11  0.00  0.09  0.09  0.00  0.00
223627 581017 59 81 70.0   0.00   4.81 0.00   4.72  0.11  0.09  1.19  0.00  0.09  0.09  0.00  0.00
223627 581018 57 82 69.5   0.00   4.72 0.00   4.64  0.10  0.08  1.28  0.00  0.08  0.08  0.00  0.00
223627 581019 52 77 64.5   0.00   4.64 0.00   4.58  0.08  0.06  1.36  0.00  0.06  0.06  0.00  0.00
223627 581020 45 80 62.5   0.00   4.58 0.00   4.53  0.07  0.05  1.42  0.00  0.05  0.05  0.00  0.00
223627 581021 47 82 64.5   0.00   4.53 0.00   4.47  0.08  0.06  1.47  0.00  0.06  0.06  0.00  0.00
```

```
STATION 223627  GREENWOOD, MS
AWC= 6.0  DEPLETION RATE=0.75

BEG.DATE  END.DATE  #DAYS
  490102    490110      9
  500105    500113      9
  511213    511222     10
  521230    530102      4
  530429    530506      8
  540428    540505      8
  550321    550328      8
  560201    560212     12
  571112    571124     13
  580919    581004     16
  590417    590421      5
  600301    600305      5
  611208    611219     12
  621224    621229      6
  631213    631224     12
  640422    640427      6
  650208    650212      5
  660209    660216      8
  671214    671221      8
  680103    680114     12
  691229    700102      5
  700105    700111      7
  710508    710514      7
  720101    720107      7
  730314    730325     12
MAX FOR TOTAL PERIOD OF RECORD
  580919    581004     16

PERCENTILES   DAYS
       0.05   14.7
       0.10   12.1
       0.25   11.5
       0.50    8.0
```

Fig. 5 Daily listing from EPA–2 for Greenwood, MS, Aug. – Oct. 1958, with summary table

```
STATION  DATE MN MX   T      P      SP   SS     SU    PE    PL    PR     R     L     ET    RO    SRO     UNF

456114 4910 4 46 55 50.5  0.68   3.96 0.73   3.85  0.06  0.06  8.04  0.62  0.00  0.06  0.00  0.00
456114 4910 5 44 60 52.0  0.18   4.58 0.84   3.85  0.06  0.06  7.42  0.12  0.00  0.06  0.00  0.00
456114 4910 6 40 52 46.0  0.34   4.69 1.00   3.99  0.04  0.04  7.31  0.12  0.00  0.04  0.00  0.00
456114 4910 7 37 61 49.0  0.00   4.99 0.95   3.99  0.05  0.05  7.01  0.00  0.05  0.05  0.00  0.00
456114 4910 8 32 55 43.5  0.01   4.94 0.92   3.99  0.03  0.03  7.06  0.00  0.02  0.03  0.00  0.00
456114 4910 9 46 60 53.0  0.43   4.92 1.00   4.28  0.07  0.07  7.08  0.00  0.00  0.07  0.00  0.00
456114 491010 42 57 49.5  0.19   5.28 1.00   4.42  0.05  0.05  6.72  0.00  0.00  0.05  0.00  0.00
456114 491011 45 60 52.5  0.31   5.42 1.00   4.66  0.06  0.06  6.58  0.00  0.00  0.06  0.00  0.00
456114 491012 36 63 49.5  0.00   5.66 0.95   4.66  0.05  0.05  6.34  0.00  0.05  0.05  0.00  0.00
456114 491013 32 58 45.0  0.00   5.61 0.91   4.66  0.04  0.04  6.39  0.00  0.04  0.04  0.00  0.00
456114 491014 29 66 47.5  0.00   5.97 0.86   4.66  0.05  0.05  6.43  0.00  0.05  0.05  0.00  0.00
456114 491015 39 61 50.0  0.04   5.53 0.85   4.66  0.05  0.05  6.47  0.00  0.01  0.05  0.00  0.00
456114 491016 32 58 45.0  0.00   5.51 0.81   4.66  0.04  0.04  6.49  0.00  0.04  0.04  0.00  0.00
456114 491017 27 53 40.0  0.02   5.48 0.81   4.66  0.02  0.02  6.52  0.00  0.00  0.02  0.00  0.00
456114 491018 27 50 38.5  0.00   5.47 0.79   4.66  0.02  0.02  6.53  0.00  0.02  0.02  0.00  0.00
456114 491019 22 52 37.0  0.00   5.46 0.78   4.66  0.01  0.01  6.54  0.00  0.01  0.01  0.00  0.00
456114 491020 23 55 39.0  0.00   5.44 0.76   4.66  0.02  0.02  6.56  0.00  0.02  0.02  0.00  0.00
456114 491021 29 58 43.5  0.00   5.43 0.73   4.66  0.03  0.03  6.57  0.00  0.03  0.03  0.00  0.00
456114 491022 29 53 41.0  0.00   5.40 0.71   4.66  0.02  0.02  6.60  0.00  0.02  0.02  0.00  0.00
456114 491023 35 49 42.0  0.00   5.37 0.68   4.66  0.03  0.03  6.63  0.00  0.03  0.03  0.00  0.00
456114 491024 37 60 48.5  0.02   5.34 0.66   4.66  0.05  0.05  6.66  0.00  0.03  0.05  0.00  0.00
456114 491025 36 51 43.5  0.01   5.32 0.63   4.66  0.03  0.03  6.68  0.00  0.02  0.03  0.00  0.00
456114 491026 43 53 48.0  0.25   5.30 0.84   4.66  0.04  0.04  6.70  0.21  0.00  0.04  0.00  0.00
456114 491027 47 57 52.0  1.24   5.50 1.00   5.69  0.06  0.06  6.50  0.21  0.00  0.06  0.00  0.00
456114 491028 45 60 52.5  1.36   6.69 1.00   6.99  0.06  0.06  5.31  0.21  0.00  0.06  0.00  0.00
456114 491029 40 57 48.5  0.01   7.99 0.96   6.99  0.05  0.05  4.01  0.00  0.04  0.05  0.00  0.00
456114 491030 36 63 49.5  0.00   7.95 0.92   6.99  0.05  0.05  4.05  0.00  0.05  0.05  0.00  0.00
456114 491031 36 74 55.0  0.00   7.90 0.85   6.99  0.07  0.07  4.10  0.00  0.07  0.07  0.00  0.00
456114 4911 1 35 65 50.0  0.00   7.84 0.80   6.99  0.05  0.05  4.16  0.00  0.05  0.05  0.00  0.00
456114 4911 2 34 72 53.0  0.00   7.79 0.74   6.99  0.06  0.06  4.21  0.00  0.06  0.06  0.00  0.00
456114 4911 3 33 71 52.0  0.00   7.73 0.69   6.99  0.05  0.05  4.27  0.00  0.05  0.05  0.00  0.00
456114 4911 4 38 74 56.0  0.00   7.68 0.62   6.99  0.07  0.07  4.32  0.00  0.07  0.07  0.00  0.00
456114 4911 5 35 64 49.5  0.00   7.61 0.57   6.99  0.05  0.05  4.39  0.00  0.05  0.05  0.00  0.00
456114 4911 6 36 52 44.0  0.00   7.56 0.54   6.99  0.03  0.03  4.44  0.00  0.03  0.03  0.00  0.00
456114 4911 7 38 55 46.5  0.19   7.53 0.70   6.99  0.04  0.04  4.47  0.15  0.00  0.04  0.00  0.00
456114 4911 8 45 51 48.0  0.25   7.68 0.91   6.99  0.04  0.04  4.32  0.21  0.00  0.04  0.00  0.00
456114 4911 9 40 48 44.0  0.14   7.89 1.00   7.00  0.03  0.03  4.11  0.21  0.00  0.03  0.00  0.00
456114 491110 42 50 46.0  0.38   8.00 1.00   7.35  0.04  0.04  4.00  0.21  0.00  0.04  0.00  0.00
456114 491111 46 53 49.5  1.16   8.35 1.00   8.46  0.05  0.05  3.65  0.21  0.00  0.05  0.00  0.00
456114 491112 45 49 47.0  2.89   9.46 1.00  11.00  0.04  0.04  2.54  0.21  0.00  0.04  0.31  0.00       X
456114 491113 46 58 52.0  0.11  12.00 1.00  11.00  0.05  0.05  0.00  0.21  0.00  0.05  0.06  0.00       X
456114 491114 45 56 50.5  0.19  12.00 1.00  11.00  0.05  0.05  0.00  0.21  0.00  0.05  0.14  0.00       X
456114 491115 40 54 47.0  0.00  12.00 0.96  11.00  0.04  0.04  0.00  0.00  0.04  0.04  0.00  0.00        003
456114 491116 40 64 52.0  0.00  11.96 0.91  11.00  0.05  0.05  0.04  0.00  0.05  0.05  0.00  0.00
456114 491117 37 55 46.0  0.04  11.91 0.92  11.00  0.03  0.03  0.09  0.01  0.00  0.03  0.00  0.00
456114 491118 45 55 50.0  0.04  11.92 0.91  11.00  0.05  0.05  0.08  0.00  0.01  0.05  0.00  0.00
456114 491119 46 51 48.5  0.00  11.91 0.87  11.00  0.04  0.04  0.09  0.00  0.04  0.04  0.00  0.00
456114 491120 38 56 47.0  0.00  11.87 0.83  11.00  0.04  0.04  0.13  0.00  0.04  0.04  0.00  0.00
456114 491121 36 50 43.0  0.05  11.83 0.86  11.00  0.03  0.03  0.17  0.02  0.00  0.03  0.00  0.00
456114 491122 37 51 44.0  0.88  11.86 1.00  11.00  0.03  0.03  0.14  0.02  0.00  0.03  0.71  0.00       X
456114 491123 48 52 50.0  0.63  12.00 1.00  11.00  0.04  0.04  0.00  0.02  0.00  0.04  0.59  0.00       X
456114 491124 50 60 55.0  0.36  12.00 1.00  11.00  0.06  0.06  0.00  0.02  0.00  0.06  0.30  0.00       X
456114 491125 48 59 53.5  0.46  12.00 1.00  11.00  0.05  0.05  0.00  0.02  0.00  0.05  0.41  0.00       X
456114 491126 50 58 54.0  2.50  12.00 1.00  11.00  0.05  0.05  0.00  0.02  0.00  0.05  2.45  1.70       X
456114 491127 43 56 49.5  1.00  12.00 1.00  11.00  0.04  0.04  0.00  0.02  0.00  0.04  0.96  1.90       X
```

```
STATION 456114  OLYMPIA, WA
AWC=12.0 DEPLETIUN RATE=0.75

BEG.DATE  END.DATE  #DAYS
  491225    500228     65
  501119    501209     21
  510109    510125     17
  520118    520126      9
  530106    530207     33
  540113    540130     18
  551111    551202     21
  560210    560309     29
  570114    570211     29
  581217    581230     14
  591209    591220     12
  600113    600129     17
  611212    611229     18
  621119    621205     17
  631112    631124     13
  641206    650110     36
  651223    660114     23
  661127    661220     24
  670313    670326     14
  681213    681224     12
  690103    690212     41
  701226    710130     36
  711202    720101     31
  720222    720313     21
  730101    730120     20
MAX FOR TOTAL PERIOD OF RECORD
  491225    500228     65

PERCENTILES   DAYS
       0.05   57.8
       0.10   38.0
       0.25   30.0
       0.50   21.0
```

Fig. 6 Daily listing from EPA–2 for Olympia, WA, Oct. 1949 – Nov. 1949, with summary table

```
STATION  DATE MN MX    T      P     SP    SS    SU     PE    PL    PR     R     L    ET    RO   SRO    UNF

456114 491128 41 52 46.5   0.54 12.00 1.00 11.00  0.03  0.03  0.00  0.02  0.00  0.03  0.51  1.66    X
456114 491129 40 47 43.5   0.34 12.00 1.00 11.00  0.03  0.03  0.00  0.02  0.00  0.03  0.31  1.22    X
456114 491130 42 51 46.5   0.18 12.00 1.00 11.00  0.03  0.03  0.00  0.02  0.00  0.03  0.15  0.62    X
456114 4912 1 47 53 50.0   0.72 12.00 1.00 11.00  0.04  0.04  0.00  0.02  0.00  0.04  0.68  0.55    X
456114 4912 2 33 49 41.0   0.44 12.00 1.00 11.00  0.02  0.02  0.00  0.02  0.00  0.02  0.42  0.22    X
456114 4912 3 30 41 35.5   0.01 12.00 1.00 11.00  0.01  0.01  0.00  0.02  0.00  0.01  0.00  0.00    X
456114 4912 4 29 51 40.0   0.02 12.00 1.00 11.00  0.02  0.02  0.00  0.02  0.00  0.02  0.00  0.00    X
456114 4912 5 35 48 41.5   0.46 12.00 1.00 11.00  0.02  0.02  0.00  0.02  0.00  0.02  0.44  0.00    X
456114 4912 6 29 45 37.0   0.00 12.00 0.99 11.00  0.01  0.01  0.00  0.00  0.01  0.01  0.00  0.00     014
456114 4912 7 26 46 36.0   0.00 11.99 0.98 11.00  0.01  0.01  0.01  0.00  0.01  0.01  0.00  0.00
456114 4912 8 25 44 34.5   0.02 11.98 1.00 11.00  0.00  0.00  0.02  0.02  0.00  0.00  0.00  0.00
456114 4912 9 27 46 36.5   0.00 12.00 0.99 11.00  0.01  0.01  0.00  0.00  0.01  0.01  0.00  0.00
456114 491210 24 43 33.5   0.00 11.99 0.99 11.00  0.00  0.00  0.01  0.00  0.00  0.00  0.00  0.00
456114 491211 26 34 30.0   0.05 11.99 1.00 11.00  0.00  0.00  0.01  0.00  0.00  0.00  0.04  0.00    X
456114 491212 32 38 35.0   0.19 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.18  0.00    X
456114 491213 36 43 39.5   0.06 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.04  0.00    X
456114 491214 37 47 42.0   0.00 12.00 0.98 11.00  0.02  0.02  0.00  0.00  0.02  0.02  0.00  0.00     003
456114 491215 36 43 39.5   0.07 11.98 1.00 11.00  0.02  0.02  0.02  0.00  0.00  0.02  0.03  0.00    X
456114 491216 32 40 36.0   0.20 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.19  0.00    X
456114 491217 32 44 38.0   0.69 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.68  0.00    X
456114 491218 26 37 31.5   0.24 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.24  0.00    X
456114 491219 17 34 25.5   0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00    X
456114 491220 22 37 29.5   0.13 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.13  0.00    X
456114 491221 36 44 40.0   0.13 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.11  0.00    X
456114 491222 42 49 45.5   0.31 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.28  0.00    X
456114 491223 40 47 43.5   1.27 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  1.25  0.50    X
456114 491224 33 49 41.0   0.00 12.00 0.98 11.00  0.02  0.02  0.00  0.00  0.02  0.02  0.00  0.00     009
456114 491225 37 49 43.0   0.66 11.98 1.00 11.00  0.02  0.02  0.02  0.00  0.00  0.02  0.62  0.00    X
456114 491226 39 43 41.0   0.78 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.76  0.01    X
456114 491227 42 48 45.0   2.94 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  2.91  2.17    X
456114 491228 46 52 49.0   0.20 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.16  1.58    X
456114 491229 31 51 41.0   0.42 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.40  1.24    X
456114 491230 31 36 33.5   0.54 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.54  1.02    X
456114 491231 30 42 36.0   0.18 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.17  0.45    X
456114 50 1 1 20 33 26.5   0.10 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.10  0.00    X
456114 50 1 2  6 25 15.5   0.06 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.06  0.00    X
456114 50 1 3  5 28 16.5   0.11 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.11  0.00    X
456114 50 1 4 23 32 27.5   0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00    X
456114 50 1 5 24 37 30.5   0.04 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.04  0.00    X
456114 50 1 6 34 37 35.5   0.86 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.85  0.10    X
456114 50 1 7 32 36 34.0   0.46 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.46  0.00    X
456114 50 1 8 30 34 32.0   0.04 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.04  0.00    X
456114 50 1 9 28 37 32.5   0.26 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.26  0.00    X
456114 50 110 31 39 35.0   0.76 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.75  0.00    X
456114 50 111 27 36 31.5   0.09 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.09  0.00    X
456114 50 112 18 32 25.0   0.11 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.11  0.00    X
456114 50 113 12 19 15.5   1.21 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  1.21  0.46    X
456114 50 114  6 21 13.5   0.07 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.07  0.00    X
456114 50 115 18 25 21.5   0.19 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.19  0.00    X
456114 50 116 16 36 26.0   0.01 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.00    X
456114 50 117  8 26 17.0   0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00    X
456114 50 118 13 26 19.5   0.38 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.38  0.00    X
456114 50 119 24 41 32.5   1.89 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  1.89  1.14    X
456114 50 120 38 46 42.0   1.07 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  1.05  1.44    X
456114 50 121 42 48 45.0   0.73 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.70  1.39    X
```

Fig. 7 Daily listing from EPA–2 for Olympia, WA, Nov. 1949 – Jan. 1950

```
STATION  DATE MN MX    T     P     SP    SS     SU     PE    PL    PR     R     L    ET    RO   SRO    UNF

456114 50 122 36 45 40.5  0.37 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.35  0.99     X
456114 50 123 23 37 30.0  0.17 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.17  0.41     X
456114 50 124 12 27 19.5  0.02 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.02  0.00     X
456114 50 125  2 31 16.5  0.06 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.06  0.00     X
456114 50 126 28 37 32.5  0.20 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.20  0.00     X
456114 50 127 22 30 26.0  0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00     X
456114 50 128  8 31 19.5  0.02 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.02  0.00     X
456114 50 129  5 26 15.5  0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00     X
456114 50 130  6 27 16.5  0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00     X
456114 50 131  1 18  9.5  0.03 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.03  0.00     X
456114 50 2 2  4 36 20.0  0.00 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00     X
456114 50 2 3  1 28 14.5  0.08 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.08  0.00     X
456114 50 2 4 27 40 33.5  0.15 12.00 1.00 11.00  0.00  0.00  0.00  0.00  0.00  0.00  0.15  0.00     X
456114 50 2 5 33 43 38.0  0.51 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.50  0.00     X
456114 50 2 6 33 42 37.5  0.55 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.54  0.00     X
456114 50 2 7 34 44 39.0  0.22 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.20  0.00     X
456114 50 2 8 34 46 40.0  0.92 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.90  0.15     X
456114 50 2 9 34 46 40.0  0.14 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.12  0.00     X
456114 50 210 33 43 38.0  0.20 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.19  0.00     X
456114 50 211 37 44 40.5  0.11 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.09  0.00     X
456114 50 212 38 46 42.0  0.95 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.92  0.17     X
456114 50 213 44 53 48.5  0.28 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.24  0.00     X
456114 50 214 42 52 47.0  0.07 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.03  0.00     X
456114 50 215 44 53 48.5  0.15 12.00 1.00 11.00  0.05  0.05  0.00  0.00  0.00  0.05  0.10  0.00     X
456114 50 216 35 53 44.0  0.05 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.02  0.00     X
456114 50 217 35 52 43.5  0.04 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.01  0.00     X
456114 50 218 37 57 47.0  0.19 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.15  0.00     X
456114 50 219 33 46 39.5  0.03 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.01  0.00     X
456114 50 220 35 48 41.5  0.06 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.03  0.00     X
456114 50 221 37 46 41.5  0.06 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.03  0.00     X
456114 50 222 40 52 46.0  0.13 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.09  0.00     X
456114 50 223 39 50 44.5  2.37 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  2.34  1.59     X
456114 50 224 40 50 45.0  0.50 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.46  1.30     X
456114 50 225 40 56 48.0  1.37 12.00 1.00 11.00  0.05  0.05  0.00  0.00  0.00  0.05  1.32  1.87     X
456114 50 226 36 53 44.5  0.53 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.49  1.62     X
456114 50 227 28 51 39.5  0.00 12.00 0.98 11.00  0.02  0.02  0.00  0.00  0.02  0.02  0.00  0.87     X
456114 50 228 26 52 39.0  0.00 11.98 0.96 11.00  0.02  0.02  0.02  0.00  0.02  0.02  0.00  0.12     X
456114 50 3 1 27 57 42.0  0.00 11.96 0.93 11.00  0.03  0.03  0.04  0.00  0.03  0.03  0.00  0.00       005
456114 50 3 2 39 50 44.5  0.62 11.93 1.00 11.00  0.04  0.04  0.07  0.00  0.00  0.04  0.52  0.00     X
456114 50 3 3 48 55 51.5  2.00 12.00 1.00 11.00  0.06  0.06  0.00  0.00  0.00  0.06  1.94  1.19     X
456114 50 3 4 41 49 45.0  1.12 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  1.08  1.52     X
456114 50 3 5 38 49 43.5  0.25 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.22  0.99     X
456114 50 3 6 31 48 39.5  0.01 12.00 0.99 11.00  0.02  0.02  0.00  0.00  0.01  0.02  0.00  0.24     X
456114 50 3 7 26 45 35.5  0.00 11.99 0.98 11.00  0.01  0.01  0.01  0.00  0.01  0.01  0.00  0.00       005
456114 50 3 8 34 48 41.0  0.11 11.98 1.00 11.00  0.03  0.03  0.02  0.00  0.00  0.03  0.07  0.00     X
456114 50 3 9 32 44 38.0  0.22 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.20  0.00     X
456114 50 310 30 45 37.5  0.14 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.13  0.00     X
456114 50 311 26 47 36.5  0.04 12.00 1.00 11.00  0.01  0.01  0.00  0.00  0.00  0.01  0.03  0.00     X
456114 50 312 33 45 39.0  0.02 12.00 1.00 11.00  0.02  0.02  0.00  0.00  0.00  0.02  0.00  0.00     X
456114 50 313 35 47 41.0  0.05 12.00 1.00 11.00  0.03  0.03  0.00  0.00  0.00  0.03  0.02  0.00     X
456114 50 314 37 48 42.5  0.00 12.00 0.97 11.00  0.03  0.03  0.00  0.00  0.03  0.03  0.00  0.00       006
456114 50 315 36 49 42.5  0.28 11.97 1.00 11.00  0.03  0.03  0.03  0.00  0.00  0.03  0.22  0.00     X
456114 50 316 43 50 46.5  0.97 12.00 1.00 11.00  0.05  0.05  0.00  0.00  0.00  0.05  0.92  0.17     X
456114 50 317 40 53 46.5  0.75 12.00 1.00 11.00  0.05  0.05  0.00  0.00  0.00  0.05  0.70  0.13     X
456114 50 318 40 47 43.5  0.90 12.00 1.00 11.00  0.04  0.04  0.00  0.00  0.00  0.04  0.86  0.24     X
```

Fig. 8 Daily listing from EPA–2 for Olympia, WA, Jan. 1950 – Mar. 1950

STATION	AWC	YEARS	MO/YR	MAX	1%	10%	25%	50%
ALABAMA								
BAY MINETTE.AL	6	1949-73	MAR 62	13	13	13	9	7
BREWTON.AL	6	1949-73	MAY 70	17	16	11	8	7
CLANTON.AL	6	1949-73	DEC 61	24	20	11	9	7
MOBILE.AL	6	1949-73	APR 55	15	14	11	10	7
SELMA.AL	6	1949-73	DEC 61	20	18	11	8	6
THOMASVILLE.AL	6	1953-74	DEC 61	25	23	13	10	8
ARKANSAS								
DUMAS.AR	6	1951-71	APR 58	19	19	14	10	7
LITTLE ROCK.AR	6	1949-72	MAY 68	12	12	12	9	7
CALIFORNIA								
LOS ANGELES.CA	7	1952-69	FEB 69	5	5	3	1	0
SAN FRANCISCO.CA	7	1949-72	JAN 69	13	13	11	5	4
FLORIDA								
AVON PARK.FL	6	1945-72	JUN 68	13	12	9	7	4
BELLE GLADE.FL	6	1951-73	OCT 52	11	10	8	8	6
DAYTONA BEACH.FL	6	1955-73	SEP 64	8	8	8	6	4
TAMPA.FL	6	1953-73	JUL 60	16	15	9	6	3
GEORGIA								
AUGUSTA.GA	6	1949-72	FEB 71	10	10	9	6	4
MACON.GA	6	1949-72	JAN 64	12	11	9	7	5
SAVANNAH.GA	6	1949-72	SEP 50	17	16	11	7	4
LOUISIANA								
HOUMA.LA	6	1950-73	MAY 59	17	16	11	8	6
LAFAYETTE.LA	6	1948-73	JAN 59	12	12	10	8	6
LAKE PROVIDENCE.LA	6	1951-72	DEC 67	19	18	14	12	7
LEESVILLE.LA	6	1950-73	APR 53	35	31	16	8	6
MONROE.LA	6	1949-72	DEC 61	12	12	12	8	7
NEW ORLEANS.LA	6	1954-73	MAY 59	16	16	9	7	6
ST. JOSEPH.LA	6	1956-73	DEC 61	12	11	11	9	6
SCHRIEVEP.LA	6	1948-73	MAR 48	16	15	13	8	7
SHREVEPORT.LA	6	1949-72	JAN 68	11	11	9	7	6
WINNFIELD.LA	6	1950-73	MAY 53	16	16	14	11	6
MISSISSIPPI								
ABERDEEN.MS	6	1951-72	DEC 61	24	23	13	9	7
BILOXI.MS	6	1951-73	SEP 57	14	13	10	8	7
CANTON.MS	6	1948-73	DEC 61	16	15	11	8	6
CLARKSDALE.MS	6	1949-72	DEC 72	18	16	11	10	8
COLUMBIA.MS	6	1947-73	FEB 61	33	27	16	10	8
MISSISSIPPI								
GREENWOOD.MS	6	1949-73	SEP 58	16	15	12	12	8
JACKSON.MS	6	1943-61	DEC 61	12	12	10	8	7
MERIDIAN.MS	6	1948-73	FEB 61	14	13	11	8	7
PONTOTOC.MS	6	1949-71	DEC 67	20	19	14	12	9
POPLARVILLE.MS	6	1945-73	DEC 61	25	22	13	8	6
STONEVILLE.MS	6	1951-72	APR 58	17	17	15	12	7
VICKSBURG.MS	6	1942-62	DEC 61	17	17	14	10	7
NORTH CAROLINA								
CHARLOTTE.NC	6	1949-73	JAN 73	12	12	11	8	6
RALEIGH.NC	6	1949-73	JAN 63	14	13	12	7	6
WELDON.NC	6	1926-50	JAN 30	11	11	10	7	5
WILMINGTON.NC	6	1949-73	JUL 50	11	10	9	8	6
OREGON								
EUGENE.OR	12	1948-73	JAN 49	35	34	31	21	15
MEDFORD.OR	12	1948-72	DEC 64	21	19	11	5	3
ROSEBURG.OR	12	1935-64	JAN 50	22	20	18	12	9
SALEM.OR	12	1948-73	DEC 49	36	34	25	17	13
SOUTH CAROLINA								
CHARLESTON.SC	6	1948-73	JUN 73	24	21	11	6	5
COLUMBIA.SC	6	1949-73	JAN 63	15	14	9	7	5
CONWAY.SC	6	1945-73	JAN 70	9	9	9	7	6
TENNESSEE								
CROSSVILLE.TN	6	1953-73	JAN 66	24	24	22	20	17
TEXAS								
ABILENE.TX	6	1950-70	JAN 61	6	6	6	3	0
AMARILLO.TX	6	1949-71	FEB 60	11	10	8	2	0
BROWNSVILLE.TX	6	1954-72	SEP 67	12	11	6	2	0
CORPUS CHRISTI.TX	6	1951-72	SEP 67	13	11	5	3	1
DALLAS.TX	6	1948-72	APR 66	15	15	12	7	4
HOUSTON.TX	6	1948-72	OCT 49	14	13	9	7	4
WICHITA FALLS.TX	6	1950-72	APR 57	8	8	6	3	3
WASHINGTON								
LONGVIEW.WA	12	1948-73	DEC 49	60	53	35	21	17
OLYMPIA.WA	12	1949-73	DEC 49	65	58	38	30	21
SEATTLE.WA	7	1949-73	DEC 49	47	40	24	14	11
SEQUIM	12	1948-73	MAR 56	6	5	3	0	0
VANCOUVER.WA	12	1924-50	JAN 50	31	28	19	17	11
WALLA WALLA.WA	7	1950-73	JAN 69	14	14	10	6	0

Fig. 9 Storage days estimated from EPA–2 program

```
STATION  1 583  BAY MINETTE, AL
AWC= 6.0     DEPLETION RATE=0.75

BEG.DATE   END.DATE   #DAYS
  490322     490329       8
  500831     500906       7
  510317     510324       8
  520215     520224      10
  531204     531216      13
  541231     550101       2
  550413     550425      13
  560311     560318       8
  570405     570412       8
  581231     590102       3
  590519     590525       7
  600402     600407       6
  611210     611218       9
  620331     620412      13
  630721     630727       7
  640108     640112       5
  650930     651009      10
  661231     670106       7
  671210     671213       4
  681231     690105       6
  690816     690823       8
  700106     700111       6
  710905     710908       4
  721221     721225       5
  730329     730401       4
MAX FOR TOTAL PERIOD OF RECORD
  620331     620412      13

PERCENTILES   DAYS
       0.05   13.0
       0.10   13.0
       0.25    8.5
       0.50    7.0
```

```
STATION 168295  SCHRIEVER, LA
AWC= 6.0  DEPLETION RATE=0.75

BEG.DATE  END.DATE   #DAYS
  480301    480317      16
  490328    490409      13
  500402    500407       6
  510328    510402       6
  520331    520406       7
  530716    530720       5
  540729    540803       6
  550206    550209       4
  560930    561008       9
  570604    570610       7
  580911    580917       7
  590530    590612      14
  601224    601226       3
  610907    610914       8
  620109    620112       4
  631109    631116       8
  641003    641009       7
  651218    651223       6
  660210    660217       8
  570205    670212       8
  681230    681231       2
  690409    690419      11
  701027    701030       4
  710907    710911       5
  721220    721224       5
  730416    730423       8
MAX FOR TOTAL PERIOD OF RECORD
  480301    480317      16

PERCENTILES   DAYS
       0.05   15.3
       0.10   13.3
       0.25    8.0
       0.50    7.0
```

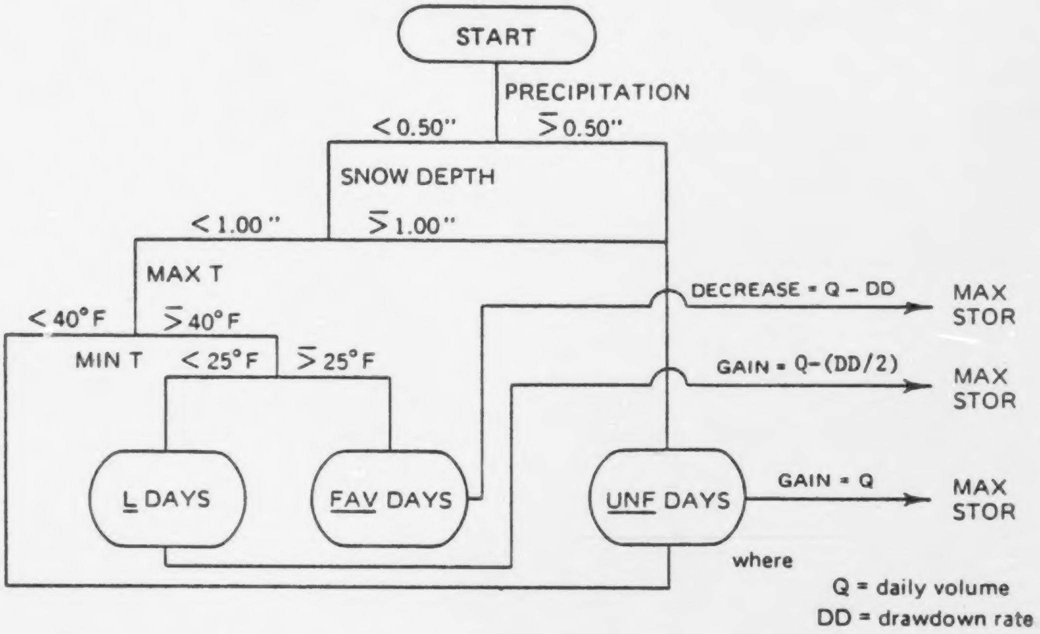
```
STATION 319191  WELDON, NC
AWC= 6.0 DEPLETION RATE=0.75

BEG.DATE  END.DATE   #DAYS
  260311    260314       4
  270110    270116       7
  280128    280201       5
  291223    291225       3
  300116    300126      11
  310112    310116       5
  321211    321220      10
  330208    330212       5
  340226    340301       4
  351223    360101      10
  360127    360202       7
  371209    371214       6
  380618    380622       5
  390825    390902       9
  400124    400201       9
  410307    410309       3
  421221    421223       3
  430214    430216       3
  441127    441201       5
  451229    460102       5
  460411    460413       3
  470118    470121       4
  480208    480213       6
  490511    490512       2
  501229    501230       3
MAX FOR TOTAL PERIOD OF RECORD
  300116    300126      11

PERCENTILES   DAYS
       0.05   10.7
       0.10   10.0
       0.25    7.0
       0.50    5.0
```

```
STATION 445120  LYNCHBURG, VA
AWC= 9.0  DEPLETION RATE=0.75

BEG.DATE  END.DATE   #DAYS
  480124    480202      10
  490103    490106       4
  500127    500202       7
  511214    511221       8
  520125    520131       7
  530102    530106       5
  540110    540118       9
  550201    550207       7
  560313    560316       4
  570205    570212       8
  580206    580220      15
  591218    591220       3
  600302    600314      13
  611227    620103       8
  621209    621215       7
  630118    630129      11
  640209    640213       5
  650130    650205       7
  661223    670101      10
  671228    680117      21
  680123    680126       4
  690120    690123       4
  700117    700124       7
  710113    710205      24
  720201    720210      10
  730126    730203       9
MAX FOR TOTAL PERIOD OF RECORD
  710113    710205      24

PERCENTILES   DAYS
       0.05   23.0
       0.10   16.8
       0.25   10.0
       0.50    7.5
```

Fig. 10 Summary tables showing annual estimated storage days for four stations (EPA–2)

SUMMARY TABLE FROM NCC–EPA–3 PROGRAM

A summary of each winter season examined shows the Freeze Index, its duration and the maximum storage days computed from the daily listings. Additional information includes the mean number of storage days, the standard deviation, unbiased third moment about the mean, the coefficient of skewness and a list of the thresholds used for each of the elements examined. The thresholds may be changed to fit individual systems or other special conditions. Storage days are also computed for recurrence intervals of 5, 10, 25 & 50—years using the Pearson Type III method. The procedure used to define each day and to compute the coefficient of skewness is shown below;


START
PRECIPITATION
< 0.50"
⩾ 0.50"
SNOW DEPTH
< 1.00"
⩾ 1.00"
MAX T
< 40° F
⩾ 40° F
MIN T
< 25° F
⩾ 25° F
L DAYS
FAV DAYS
UNF DAYS
DECREASE = Q – DD
GAIN = Q–(DD/2)
GAIN = Q
MAX STOR
MAX STOR
MAX STOR
where
Q = daily volume
DD = drawdown rate

1. Using the values in the "MAX STOR" column, compute the mean storage days ($\bar{x}$) and the standard deviation (σ).
2. Cube the difference between each storage value and the mean $(\text{STOR}-\bar{x})^3$ and sum algebraically.
3. Compute the unbiased third moment about the mean: $a = \frac{N\Sigma(\text{STOR}-\bar{x})^3}{(N-1)(N-2)}$
4. Compute the coefficient of skewness: $C_s = \frac{a}{\sigma^3}$
5. Enter table with C_s and recurrence interval to find k.
6. Storage days are then equal to $\bar{x} + k\sigma$.

Fig. 11 Outline of the procedure used in developing the summary table for EPA–3 shown in Fig. 12

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS   TABLE 1   EPA-3              05/13/76
STA #  485390  LANDER, WY                                            POR: 481101-740430
                         HIGH TO LOW FREEZE INDEX
                                 DATE                     MAX     MAX     MAX      MAX                 MAX
                    INDX     BEGIN       END       DUR     FA     UNF    STOR   (STOR-MN)          (STOR-MN)3

                    2154     721110     730410     151      7     149  169.00       64.24               265104
                    1880     481103     490314     131     16     109  128.00       23.24                12552
                    1704     611101     620316     135     14     103  123.50       18.74                 6581
                    1397     671101     680218     109     10     105  129.75       24.99                15606
                    1357     551110     560315     125     19      46  109.00        4.24                   76
                    1286     591103     600317     134     39      98  126.50       21.74                10275
                    1230     631206     640328     112     19     102  121.00       16.24                 4283
                    1156     511113     520325     132     28      48  106.75        1.99                    8
                    1075     541127     550328     121     27      59  111.00        6.24                  243
                    1035     711101     720215     106     21     112  114.75        9.99                  997
                    1010     581114     590315     121     10      47  123.75       18.99                 6848
                    1005     681123     690315     112     12      29  104.25        -.51                    0
                     985     621219     630317      88     14      42   73.50      -31.26               -30547
                     883     561113     570207      86     14      58  101.25       -3.51                  -43
                     879     641110     650328     138     17      24   88.00      -16.76                -4708
                     863     491202     500214      74     35      48   73.00      -31.76               -32036
                     836     731118     740225      99     15      31   90.75      -14.01                -2750
                     822     651211     660307      86     23      45   87.25      -17.51                -5369
                     812     601102     610308     126     10      78  115.25       10.49                 1154
                     752     521115     530306     111     11      40  102.00       -2.76                  -21
                     733     701209     710307      88     16      44   81.50      -23.26               -12584
                     698     571101     580320     139     13      50  115.50       10.74                 1239
                     664     501107     510319     132      9      18   77.75      -27.01               -19705
                     560     661130     670308      98     15      25   82.00      -22.76               -11790
                     495     691116     700404     139     13      25   90.25      -14.51                -3055
                     413     531117     540331     134     17      14   78.50      -26.26               -18109

STORAGE DATA  N = 26   MEAN = 104.76   SD =  22.45  A =    7984   (STOR-MN)3 = 184249  CS =     .70

   AVERAGE INDEX   1026
                                                                                     RECURRENCE INTV
   PERCENTILES                                 151                 169.00
   MAX            2154                         146                 153.30          STOR05 =  122.50
    5%            2044                         139                 128.55          STOR10 =  134.69
   10%            1757                         134                 121.50          STOR25 =  148.93
   25%            1241                         121                 105.45          STOR50 =  158.81
   50%             934

   THRESHOLDS :  32 F,     1 DEPTH,     .50 PRECIP,   1.50 RATE  < 25 F, MIN  < 40 F, MAX
```

Fig. 12 Summary of 26 winter seasons at Lander, WY from the EPA-3 program (see Figs. 13–18 for the daily listings)

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS             EPA-3         05/13/76
STA #  485390  LANDER, WY                                          POR: 481101-740430
                               SNOW                                    DUR        DUR     MAX
YR  MO  DA    MAX   MIN  MEAN  DPTH   PPPP  FOG      DD     CDD   FA    FA  UNF   UNF    STOR

48  11  01     60    30    45                        13      13    X
48  11  02     57    33    45                        13      26    X
48  11  03     59    31    45                        13      39    X
48  11  04     38    24    31                        -1      38          3    X          1.00
48  11  05     49    15    32                         0      38               L     1    1.25
48  11  06     47    17    32                         0      38               L          1.50
48  11  07     30    13    22     5    .41          -10      28          2    X          2.50
48  11  08     30     4    17     4                 -15      13               X          3.50
48  11  09     39     9    24     2                  -8       5               X          4.50
48  11  10     37    21    29     2    .01           -3       2               X          5.50
48  11  11     35    17    26     2                  -6      -4               X          6.50
48  11  12     46    21    34     1                   2      -2               X          7.50
48  11  13     53    28    41     T                   9       7    X                6    7.00
48  11  14     58    28    43     T                  11      18    X                     6.50
48  11  15     53    26    40                         8      26    X                     6.00
48  11  16     48    21    35                         3      29               L          6.25
48  11  17     44    18    31     T    .01           -1      28               L          6.50
48  11  18     33    15    24                        -8      20          5    X          7.50
48  11  19     27    10    19          .16          -13       7               X          8.50
48  11  20     34    23    29     7    .45           -3       4               X          9.50
48  11  21     34    10    22     9    .18          -10      -6               X         10.50
48  11  22     35     4    20     8                 -12     -18               X         11.50
48  11  23     39    14    27     6                  -5     -23               X         12.50
48  11  24     45    21    33     4                   1     -22               X         13.50
48  11  25     35    14    25     3                  -7     -29               X         14.50
48  11  26     31    12    22     3    .01          -10     -39               X         15.50
48  11  27     25     5    15     3                 -17     -56               X         16.50
48  11  28     39     4    22     3                 -10     -66               X         17.50
48  11  29     37    11    24     2                  -8     -74               X         18.50
48  11  30     29     5    17     2                 -15     -89               X         19.50
```

Fig. 13 Listing of daily data from EPA–3 program, Lander, WY, November 1948

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS                EPA-3              05/13/76
STA #  485390  LANDER, WY                                               POR: 481101-740430
                                      SNOW                                                  DUR            DUR     MAX
YR   MO   DA    MAX    MIN   MEAN   DPTH     PPPP   FOG     DD     CDD     FA     FA   UNF    UNF    STOR

48   12   01     33     16     25      2                    -7     -96                    X           20.50
48   12   02     52     17     35      1                     3     -93                    X           21.50
48   12   03     48     38     43      1                    11     -82                    X           22.50
48   12   04     40      7     24      2      .24           -8     -90                    X           23.50
48   12   05     26      0     13      3                   -19    -109                    X           24.50
48   12   06     31      8     20      3                   -12    -121                    X           25.50
48   12   07     24      5     15      3                   -17    -138                    X           26.50
48   12   08     32      9     21      2                   -11    -149                    X           27.50
48   12   09     35      3     19      2                   -13    -162                    X           28.50
48   12   10     40     19     30      2                    -2    -164                    X           29.50
48   12   11     40     22     31      2                    -1    -165                    X           30.50
48   12   12     43     29     36      1                     4    -161                    X           31.50
48   12   13     34     21     28      1                    -4    -165                    X           32.50
48   12   14     23     16     20      1      .01          -12    -177                    X           33.50
48   12   15     26     10     18      1                   -14    -191                    X           34.50
48   12   16     23      5     14      1                   -18    -209                    X           35.50
48   12   17     21      3     12      1                   -20    -229                    X           36.50
48   12   18     27      7     17      1                   -15    -244                    X           37.50
48   12   19     34     14     24      1                    -8    -252                    X           38.50
48   12   20     42     17     30      1                    -2    -254                    X           39.50
48   12   21     25      6     16      1                   -16    -270                    X           40.50
48   12   22     22      1     12      1                   -20    -290                    X           41.50
48   12   23     17     11     14      2      .32          -18    -308                    X           42.50
48   12   24     18      0      9      6      .02    F     -23    -331                    X           43.50
48   12   25      3    -14     -6      6             F     -38    -369                    X           44.50
48   12   26      5    -17     -6      6                   -38    -407                    X           45.50
48   12   27     15    -12      2      5                   -30    -437                    X           46.50
48   12   28     32      7     20      5                   -12    -449                    X           47.50
48   12   29     19      3     11      4                   -21    -470                    X           48.50
48   12   30     27      1     14      3                   -18    -488                    X           49.50
48   12   31     23      1     12      3                   -20    -508                    X           50.50
```

Fig. 14 Listing of daily data from EPA—3 program, Lander, WY, December 1948

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS                      EPA-3           05/13/76
STA #  485390  LANDER, WY                                                    POR: 481101-740430
                                      SNOW                                               DUR           DUR      MAX
YR   MO   DA    MAX    MIN   MEAN   DPTH     PPPP   FOG     DD     CDD    FA       FA   UNF      UNF     STOR

49   01   01     23      3     13      3                    -19    -527                   X               51.50
49   01   02     21      7     14      6      .10           -18    -545                   X               52.50
49   01   03      8      1      5      7      .21    F      -27    -572                   X               53.50
49   01   04     16      1      9      9      .05           -23    -595                   X               54.50
49   01   05     25      1     13      8                    -19    -614                   X               55.50
49   01   06     22     -2     10      8                    -22    -636                   X               56.50
49   01   07     23      3     13      7                    -19    -655                   X               57.50
49   01   08     30     -1     15      7      .07    F      -17    -672                   X               58.50
49   01   09     -1    -15     -8      9      .11           -40    -712                   X               59.50
49   01   10     -1    -15     -8     10      .09           -40    -752                   X               60.50
49   01   11      7     -8     -1     10      .07           -33    -785                   X               61.50
49   01   12      5    -14     -5      9             F      -37    -822                   X               62.50
49   01   13     13      0      7      9             F      -25    -847                   X               63.50
49   01   14     35      3     19      9             F      -13    -860                   X               64.50
49   01   15     25     12     19      9      .04           -13    -873                   X               65.50
49   01   16     18     -5      7      9                    -25    -898                   X               66.50
49   01   17      6    -12     -3      9                    -35    -933                   X               67.50
49   01   18     18     -5      7      9      .02           -25    -958                   X               68.50
49   01   19      5    -12     -4      9                    -36    -994                   X               69.50
49   01   20     -5    -21    -13      9                    -45   -1039                   X               70.50
49   01   21      7    -19     -6      9                    -38   -1077                   X               71.50
49   01   22     14      0      7     10      .24           -25   -1102                   X               72.50
49   01   23      1    -23    -11     17      .26           -43   -1145                   X               73.50
49   01   24    -12    -31    -22     17                    -54   -1199                   X               74.50
49   01   25     -8    -31    -20     17                    -52   -1251                   X               75.50
49   01   26      2    -25    -12     17                    -44   -1295                   X               76.50
49   01   27     10    -16     -3     16      .22           -35   -1330                   X               77.50
49   01   28     13     -7      3     19      .14           -29   -1359                   X               78.50
49   01   29      2    -15     -7     17                    -39   -1398                   X               79.50
49   01   30     14     -8      3     15                    -29   -1427                   X               80.50
49   01   31     13     -7      3     15      .03           -29   -1456                   X               81.50
```

Fig. 15 Listing of daily data from EPA–3 program, Lander, WY, January 1949

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS            EPA-3               05/13/76
STA #  485390  LANDER, WY                                           POR: 481101-740430
                                         SNOW                                          DUR             DUR     MAX
YR   MO   DA     MAX    MIN   MEAN   DPTH     PRPP   FOG       DD      CDD     FA      FA    UNF     UNF    STOR

49   02   01      -2    -17    -10     15                     -42    -1498                    X             82.50
49   02   02      -1    -19    -10     15                     -42    -1540                    X             83.50
49   02   03       2    -19     -9     15                     -41    -1581                    X             84.50
49   02   04      25    -14      6     15                     -26    -1607                    X             85.50
49   02   05      21      2     12     15                     -20    -1627                    X             86.50
49   02   06      25     -6     10     15                     -22    -1649                    X             87.50
49   02   07      27      9     18     15      .01            -14    -1663                    X             88.50
49   02   08      22      5     14     15                     -18    -1681                    X             89.50
49   02   09      30      2     16     14                     -16    -1697                    X             90.50
49   02   10      46     11     29     10                      -3    -1700                    X             91.50
49   02   11      38      6     22     10      .15            -10    -1710                    X             92.50
49   02   12       6    -16     -5     12      .23            -37    -1747                    X             93.50
49   02   13       7    -28    -11     12                     -43    -1790                    X             94.50
49   02   14      18     -8      5     11                     -27    -1817                    X             95.50
49   02   15      32      1     17     11                     -15    -1832                    X             96.50
49   02   16      44      8     26     10                      -6    -1838                    X             97.50
49   02   17      50     22     36      9                       4    -1834                    X             98.50
49   02   18      49     32     41      8                       9    -1825                    X             99.50
49   02   19      46     26     36      6                       4    -1821                    X            100.50
49   02   20      36     17     27      6                      -5    -1826                    X            101.50
49   02   21      42     21     32      5                       0    -1826                    X            102.50
49   02   22      47     20     34      5                       2    -1824                    X            103.50
49   02   23      45     25     35      3                       3    -1821                    X            104.50
49   02   24      37     15     26      2                      -6    -1827                    X            105.50
49   02   25      43     17     30      2                      -2    -1829                    X            106.50
49   02   26      39     23     31      2                      -1    -1830                    X            107.50
49   02   27      38     19     29      2                      -3    -1833                    X            108.50
49   02   28      40     17     29      2                      -3    -1836                    X            109.50
```

Fig. 16 Listing of daily data from EPA—3 program, Lander, WY, February 1949

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS                 EPA-3           05/13/75
STA # 485390  LANDER, WY                                              PORI 48[illegible]01-74C430
                                   SNOW                                                DUR            DUR      MAX
YR   MO   DA    MAX    MIN   MEAN  DPTH      PPPP   FOG      DD     CDD     FA      FA   UNF     UNF     STLR

49   03   01     43     18     31     2                      -1   -1837                   X            110.50
49   03   06     49     25     37     1                       5   -1832                   X            111.50
49   03   07     46     25     36     1                       4   -1828                   X            112.50
49   03   08     36     27     32     1       .07             0   -1828                   X            113.50
49   03   09     44     18     31     1                      -1   -1829                   X            114.50
49   03   10     36     18     27     1                      -5   -1834                   X            115.50
49   03   11     40     22     31     T                      -1   -1835                   L        109 115.75
49   03   12     39     25     32     T       .05             0   -1835             1     X            116.75
49   03   13     49     23     36     T                       4   -1831                   L          1 117.00
49   03   14     32     11     22     T                     -10   -1841             1     X            118.00
49   03   15     53     13     33     T                       1   -1840                   L          1 118.25
49   03   16     39     25     32     T                       0   -1840             1     X            119.25
49   03   17     51     21     36     T                       4   -1836                   L          1 119.50
49   03   18     54     27     41     T                       9   -1827      X                         119.00
49   03   19     62     30     46     T                      14   -1813      X                         118.50
49   03   20     57     30     44     T       .25            12   -1801      X                         118.00
49   03   21     50     25     38                             6   -1795      X                         117.50
49   03   22     50     28     39                             7   -1768      X                         117.00
49   03   23     37     28     33     7      1.19             1   -1787             6     X            118.00
49   03   24     32     20     26    13       .10            -6   -1793                   X            119.00
49   03   25     40     12     26     7                      -6   -1799                   X            120.00
49   03   26     41     22     32     4                       0   -1799                   X            121.00
49   03   27     42     20     31     3                      -1   -1800                   X            122.00
49   03   28     33     14     24     3       .04            -8   -1808                   X            123.00
49   03   29     29     21     25     4       .17            -7   -1815                   X            124.00
49   03   30     39     18     29     1                      -3   -1818                   X            125.00
49   03   31     39     23     31     1       .01            -1   -1819                   X            126.00
```

Fig. 17 Listing of daily data from EPA—3 program, Lander, WY, March 1949

```
USE OF CLIMATIC DATA IN DESIGN OF SOILS TREATMENT SYSTEMS                 EPA-3              05/13/76
STA #  485390  LANDER, WY                                            PORI 481101-740430
                                      SNOW                                          DUR              DUR      MAX
YR   MO   DA    MAX    MIN   MEAN   DPTH     PPPP   FOG     DD     CDD    FA       FA   UNF      UNF     STOR

49   04   01     41     23     32      1                     0   -1819                   X               127.00
49   04   02     46     22     34      1                     2   -1817                   X               128.00
49   04   03     51     32     42      T                    10   -1807    X                         11  127.50
49   04   04     57     31     44      T                    12   -1795    X                             127.00
49   04   05     60     32     46                           14   -1781    X                             126.50
49   04   06     62     31     47                           15   -1766    X                             126.00
49   04   07     67     35     51                           19   -1747    X                             125.50
49   04   08     58     37     48               .32         16   -1731    X                             125.00
49   04   09     47     32     40                            8   -1723    X                             124.50
49   04   10     59     27     43                           11   -1712    X                             124.00
49   04   11     73     34     54                           22   -1690    X                             123.50
49   04   12     63     40     52                           20   -1670    X                             123.00
49   04   13     49     32     41      T        .15          9   -1661    X                             122.50
49   04   14     39     29     34      T        .48    F     2   -1659            11      X             123.50
49   04   15     59     23     41                            9   -1650                    L          1  123.75
49   04   16     68     35     52                           20   -1630    X                             123.25
49   04   17     64     37     51                           19   -1611    X                             122.75
49   04   18     69     34     52                           20   -1591    X                             122.25
49   04   19     70     39     55                           23   -1568    X                             121.75
49   04   20     60     38     49                           17   -1551    X                             121.25
49   04   21     66     34     50                           18   -1533    X                             120.75
49   04   22     64     40     52                           20   -1513    X                             120.25
49   04   23     75     41     58                           26   -1487    X                             119.75
49   04   24     78     50     64                           32   -1455    X                             119.25
49   04   25     70     45     58                           26   -1429    X                             118.75
49   04   26     65     42     54                           22   -1407    X                             118.25
49   04   27     71     40     56                           24   -1383    X                             117.75
49   04   28     77     42     60                           28   -1355    X                             117.25
49   04   29     69     42     56               .04         24   -1331    X                             116.75
49   04   30     55     35     45                           13   -1318    X       16                    116.25

FREEZE INDEX       1880     481103      490314      131                             16              109 128.00
```

Fig. 18 Listing of daily data from EPA–3 program, Lander, WY, April 1949

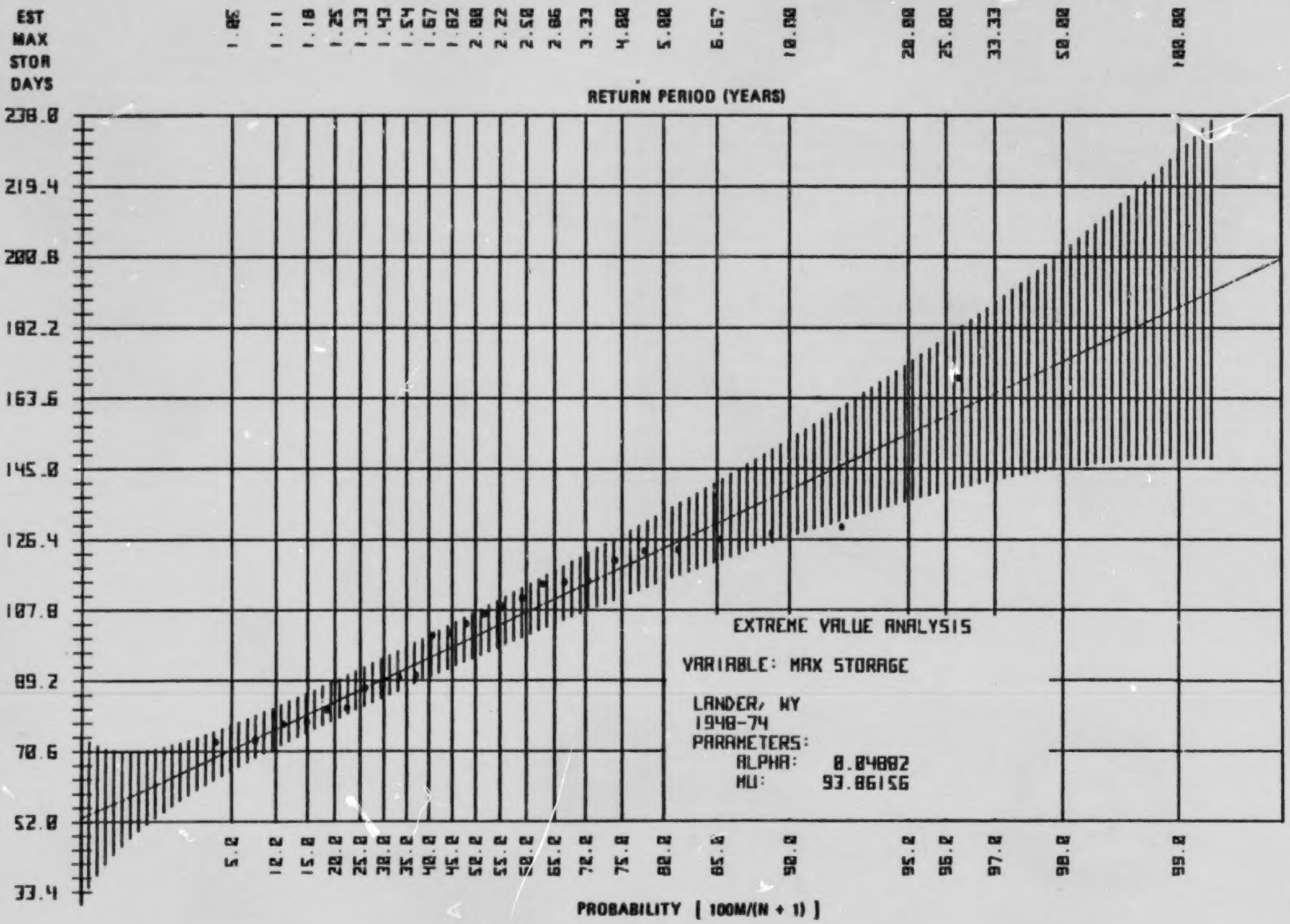


Fig. 18A Estimated maximum annual storage days for return periods to 100 years (Gumbel)

93

STATION	5-YR	10-YR	25-YR	50-YR	PERIOD	DD
BELLE PLAINE,IA	104.3	112.7	121.9	128.0	11/48-04/73	1.50
DES MOINES,IA	98.3	105.8	113.9	119.1	11/48-04/73	1.50
GRINNELL,IA	102.1	110.0	118.8	124.7	11/48-04/73	1.50
HAMPTON,IA	121.2	130.6	141.2	148.4	11/49-04/72	1.50
INDIANOLA,IA	85.5	93.9	103.1	109.2	11/48-04/73	1.50
KEOSAUQUA,IA	77.2	84.9	93.5	99.3	11/48-04/73	1.50
KNOXVILLE,IA	87.4	96.8	107.5	114.7	11/49-04/70	1.50
LOGAN,IA	93.1	105.6	110.6	116.5	11/47-04/73	1.50
NEWTON,IA	97.6	106.9	116.9	123.5	11/52-04/72	1.50
OSCEOLA,IA	79.1	87.3	96.3	102.3	11/48-04/67	1.50
OSKALOOSA,IA	90.8	99.1	108.3	114.4	11/46-04/73	1.50
SHENANDOAH,IA	75.3	83.3	92.0	97.7	11/48-04/73	1.50
WINTERSET,IA	96.5	105.4	115.0	121.2	11/53-04/73	1.50
BALTIMORE,MD	51.8	57.4	63.4	67.3	11/50-04/72	1.25
BALTIMORE,MD	48.8	54.8	61.4	65.7	11/50-04/72	1.33
BALTIMORE,MD	43.0	49.9	57.7	63.0	11/50-04/72	1.50
CROSSVILLE,TN	48.3	53.9	60.1	64.3	11/53-04/73	1.50
DIVERSON DAM,WY	80.7	88.8	98.0	104.7	11/48-04/74	1.50
LANDER,WY	122.5	134.7	148.9	158.8	11/48-04/74	1.50
PAVILLION,WY	85.3	92.4	100.1	105.2	11/48-04/74	1.50
RIVERTON,WY	100.2	105.7	111.6	115.5	11/47-04/74	1.50
RIVERTON,WY	102.1	110.3	119.5	125.8	11/22-04/47	1.50

Table 4 Estimated storage days for indicated return periods from the EPA–3 program. Note the effect of changing the drawdown rate (DD) at Baltimore and the period of record at Riverton.

APPENDIX B.

SUPPLEMENTAL INFORMATION

The tables in Figure 42 show the calendar dates in spring (in fall) after which (before which) threshold temperatures, or lower, may be expected for nine probability levels. The actual dates of the last occurrence in spring and the first occurrence in the fall are recorded and the number of days between these dates each year is computed. These periods are defined as the length of the growing season, the freeze-free period, or simply the number of days between the indicated threshold temperatures. The number of days from the first freeze in fall to the last freeze in spring is sometimes referred to as the dormant period.

This period is not the same as the Freeze Index described in the EPA-1 program which is computed by accumulating the daily differences between the mean daily temperature and 32° F. The freeze tables described in the previous paragraph are computed from daily minimum temperatures instead of the mean temperature. Another difference is that the freeze tables make no provision for the effect of warmer days that may follow the first low temperature in the fall, or those that precede the last one in the spring, while the Freeze Index does.

Hourly observations of surface wind direction and speed, including peak gusts, are taken routinely at most airport stations. Daily peak gusts are also reported at many of these stations. A variety of wind summaries covering 5 to 10 years of record are readily available at the NCC and can be furnished for the cost of duplication. Caution should be exercised in using wind summaries, since many of them are prepared for special applications. Some of these include low ceiling-visibility-wind distributions or all weather wind graphs for airport master plans (Figure 19) and extreme wind probabilities for design purposes (Figures 20 and 21). Stations in coastal or mountain regions usually have quite different day and night wind patterns. The wind distribution at the proposed site may be influenced by local conditions and, therefore, quite different from that at the nearest reporting station. Special wind equipment might be installed at the proposed site if conditions warrant; however, analyses of wind direction and speed should be based on at least five or more years of record in order to obtain a representative distribution.

Thom [20] has chosen the annual extreme fastest mile wind speed as the best available measure of wind for design purposes. He found that only airport or open country wind data could be used because of unknown surface friction conditions at city office exposures. Figures (20) and (21) are from Thom's paper and show the 10-year and 25-year mean recurrence intervals in miles per hour. The charts are based on 21 years of record; however, suitable adjustments must be made to the values where experience indicates the wind speeds in the figures are inadequate. These conditions can exist where unusual channeling occurs, such as the Santa Ana in California and the winds along the eastern slopes of the Rockies, especially in the region of Boulder and Colorado Springs.

Thunderstorms and tropical cyclones generally produce their high winds during the summer months, while the highest wind speeds in winter are usually caused by extratropical cyclones. Tropical cyclones are often accompanied by tornadoes and the effects of a well developed tropical storm can extend inland for several hundred miles. Tropical storms that move along the Atlantic coastline in a northeasterly direction can remain intense systems as far north as Maine. According to Thom, thunderstorms account for about one-third of the extreme wind speeds in this country.

Mountain and valley winds move along the axis of a valley [21], blowing uphill (valley wind) by day and downhill (mountain wind) by night. The valley wind sets in about one-half hour after sunrise and continues until about one-half hour before sunset, reaching its greatest strength at the time of maximum insolation along the slopes. On southerly slopes it may reach 14 mph, while on the north facing slopes it is barely noticeable. The mountain wind is due to nocturnal cooling and is somewhat weaker, reaching perhaps 9 mph on occasion, but it is usually stronger a few hundred feet above the ground than at the surface. Detailed information about mixing heights, stability and wind patterns in the upper air are also available [22]. Additional information of interest to planners may be found in the literature [23, 24, 25, 26, 27, 28, 29].

Note: The values in Figures 25-27 are roughly equivalent to the minimum temperatures which have an average return period of 100 years (1%), 33 years (3%) and 20 years (5%).

SUPPLEMENTAL INFORMATION

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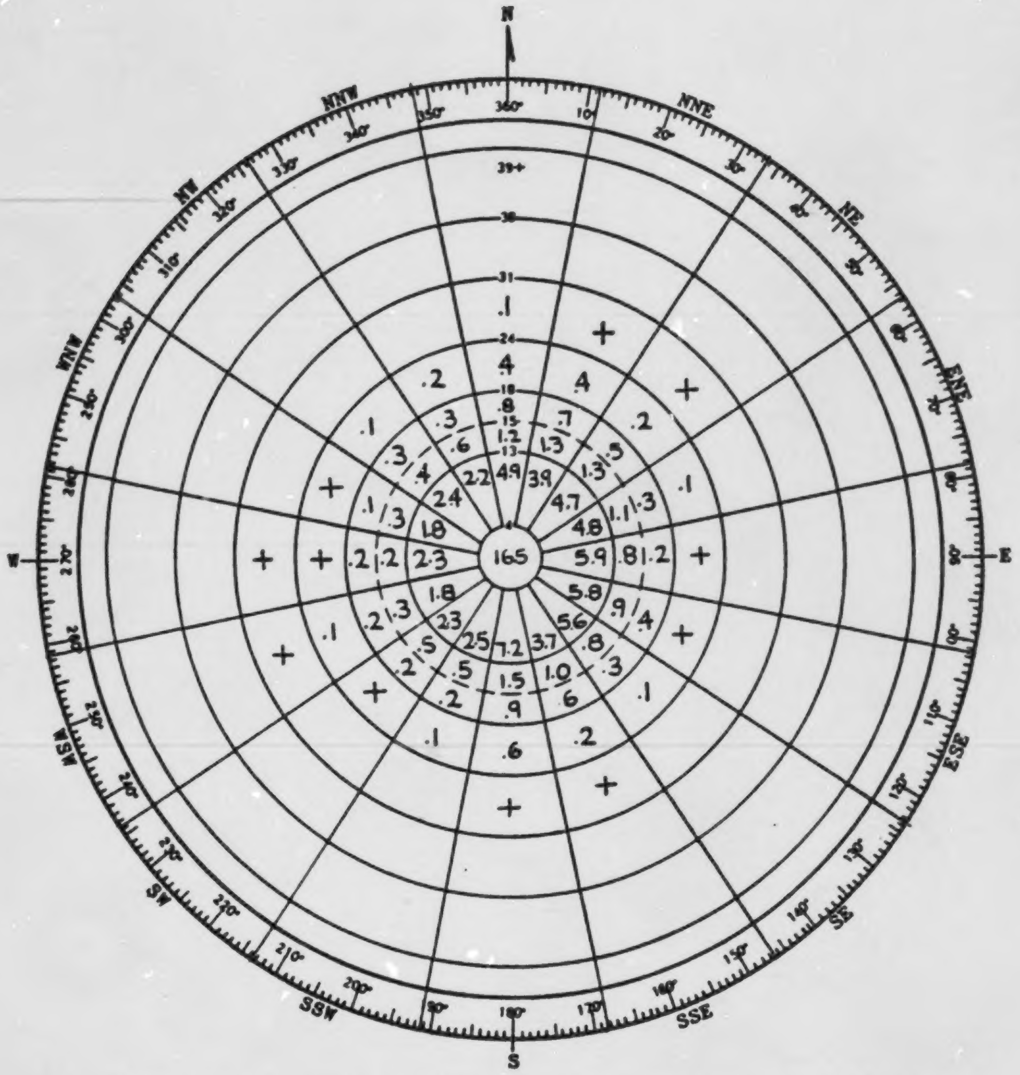


THE WIND ROSE IS A SCALED GRAPHICAL PRESENTATION OF SURFACE WIND DATA IN TERMS OF SPEED AND DIRECTION. THE RADIAL LINES OF THE DIAGRAM ARE POSITIONED SO THAT AREAS BETWEEN THEM ARE CENTERED ON THE DIRECTION FROM WHICH THE WINDS ARE REPORTED. THE CONCENTRIC CIRCLES REPRESENT LIMITS BETWEEN SPEED GROUPS SECTORS, I.E., 4, 13, 15, 18, 24, 31, 38, AND 39+ MILES PER HOUR. RADII FOR THESE GROUPS ARE ACCURATELY SCALED TO THE RESPECTIVE SPEEDS. THE SEGMENTS ENCLOSED BY RADIAL LINES AND CONCENTRIC CIRCLES ON THE DIAGRAM REPRESENT WIND SPEED-DIRECTION COMBINATIONS. THE DATA FROM A WIND SUMMARY ARE TRANSFERRED TO THE APPROPRIATE AREA ON THE DIAGRAM AS A PERCENTAGE OF THE TOTAL OBSERVATIONS EXAMINED.

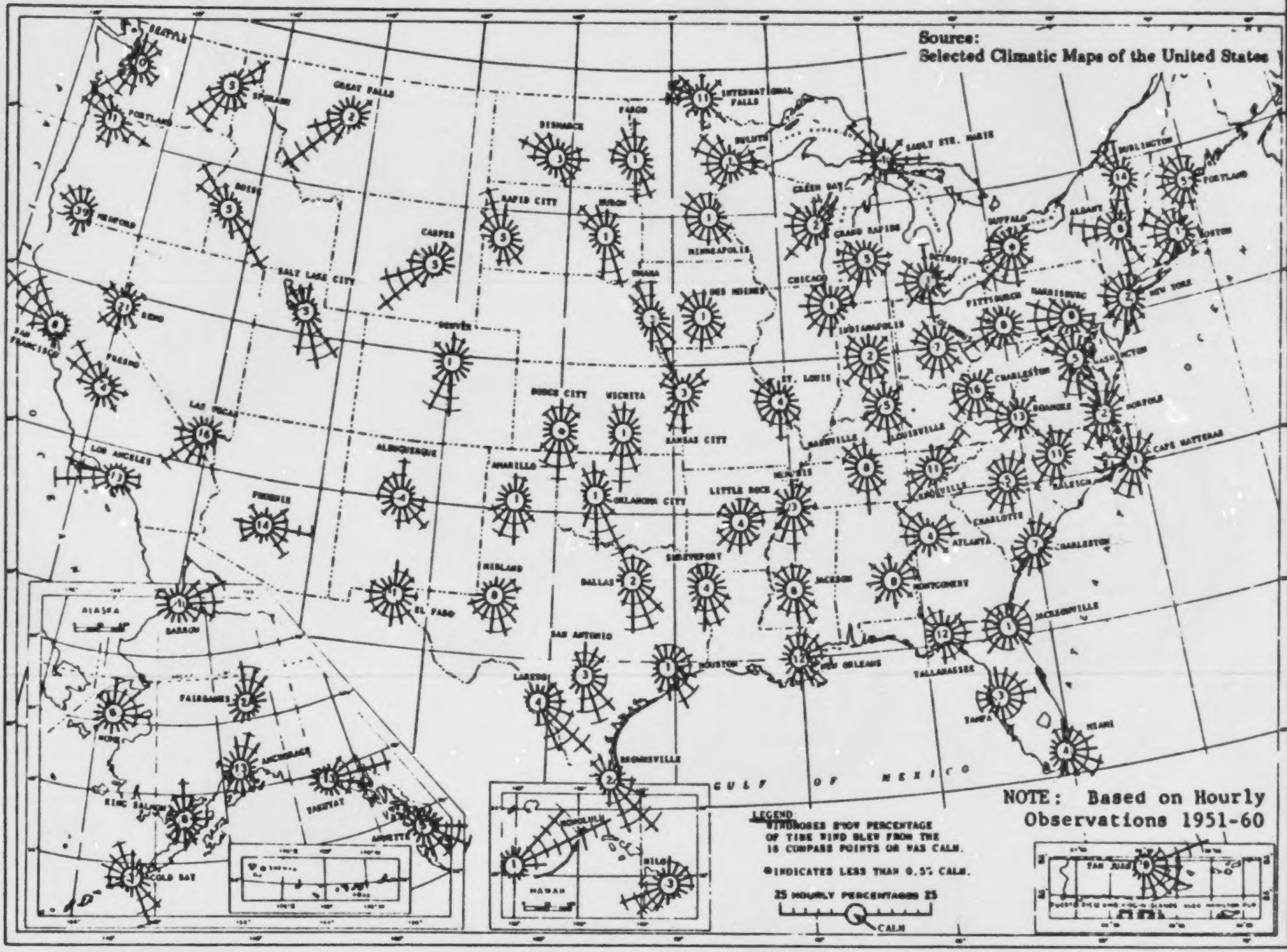
16.5 % of the winds were less than 4 m.p.h.

based on 11,576 observations

+ indicates less than 0.05

Fig. 19 Annual distribution of surface wind direction and speed, Boothville, LA, May 1971 – April 1975, 8 observations per day, all weather conditions

105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MEDFORD
BOISE
RENO
SAN FRANCISCO
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LAS VEGAS
LOS ANGELES
SALT LAKE CITY
CASPER
RAPID CITY
BISMARCK
FARGO
HURON
INTERNATIONAL FALLS
DULUTH
MINNEAPOLIS
SAULT STE. MARIE
GREEN BAY
GRAND RAPIDS
CHICAGO
DETROIT
BUFFALO
ALBANY
BURLINGTON
PORTLAND
BOSTON
NEW YORK
OMAHA
DES MOINES
DENVER
PHOENIX
ALBUQUERQUE
DODGE CITY
WICHITA
KANSAS CITY
ST. LOUIS
INDIANAPOLIS
COLUMBUS
PITTSBURGH
HARRISBURG
WASHINGTON
CHARLESTON
LOUISVILLE
NASHVILLE
ROANOKE
NORFOLK
CAPE HATTERAS
RALEIGH
KNOXVILLE
CHARLOTTE
ATLANTA
CHARLESTON
AMARILLO
OKLAHOMA CITY
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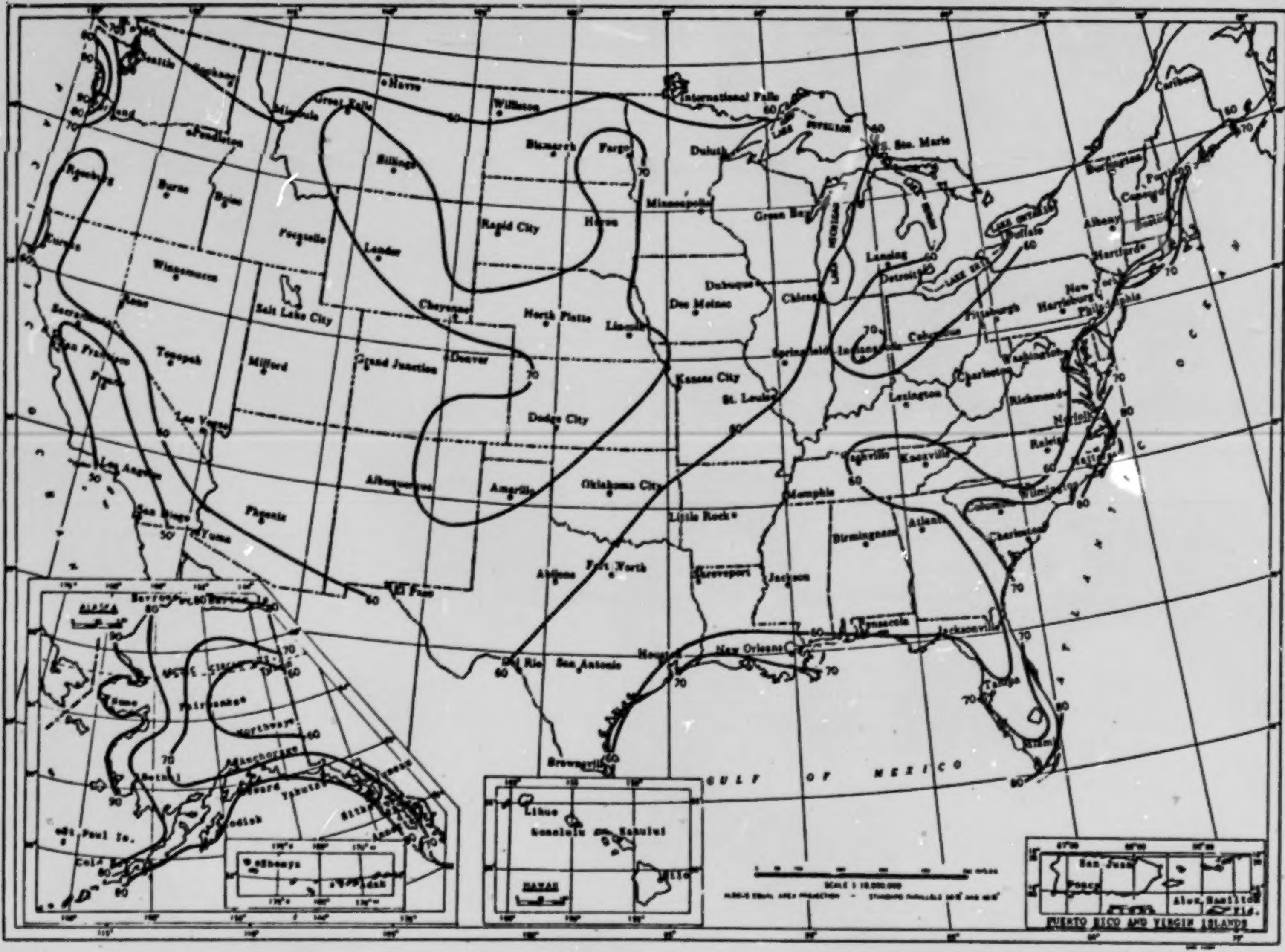
MEMPHIS
SHREVEPORT
DALLAS
MIDLAND
EL PASO
JACKSON
MONTGOMERY
JACKSONVILLE
TALLAHASSEE
SAN ANTONIO
HOUSTON
NEW ORLEANS
LAREDO
BROWNSVILLE
TAMPA
MIAMI
GULF OF MEXICO
ALASKA
BARROW
FAIRBANKS
NOME
ANCHORAGE
YAKUTAT
KING SALMON
ANNETTE
COLD BAY
HAWAII
HONOLULU
HILO
SAN JUAN

Source:
Selected Climatic Maps of the United States

NOTE: Based on Hourly Observations 1951-60

LEGEND
WINDROSES SHOW PERCENTAGE OF TIME WIND BLEW FROM THE 16 COMPASS POINTS OR WAS CALM.
⊕ INDICATES LESS THAN 0.5% CALM.
25 HOURLY PERCENTAGES 25
CALM

Fig. 20 Surface wind roses, annual, 1951–60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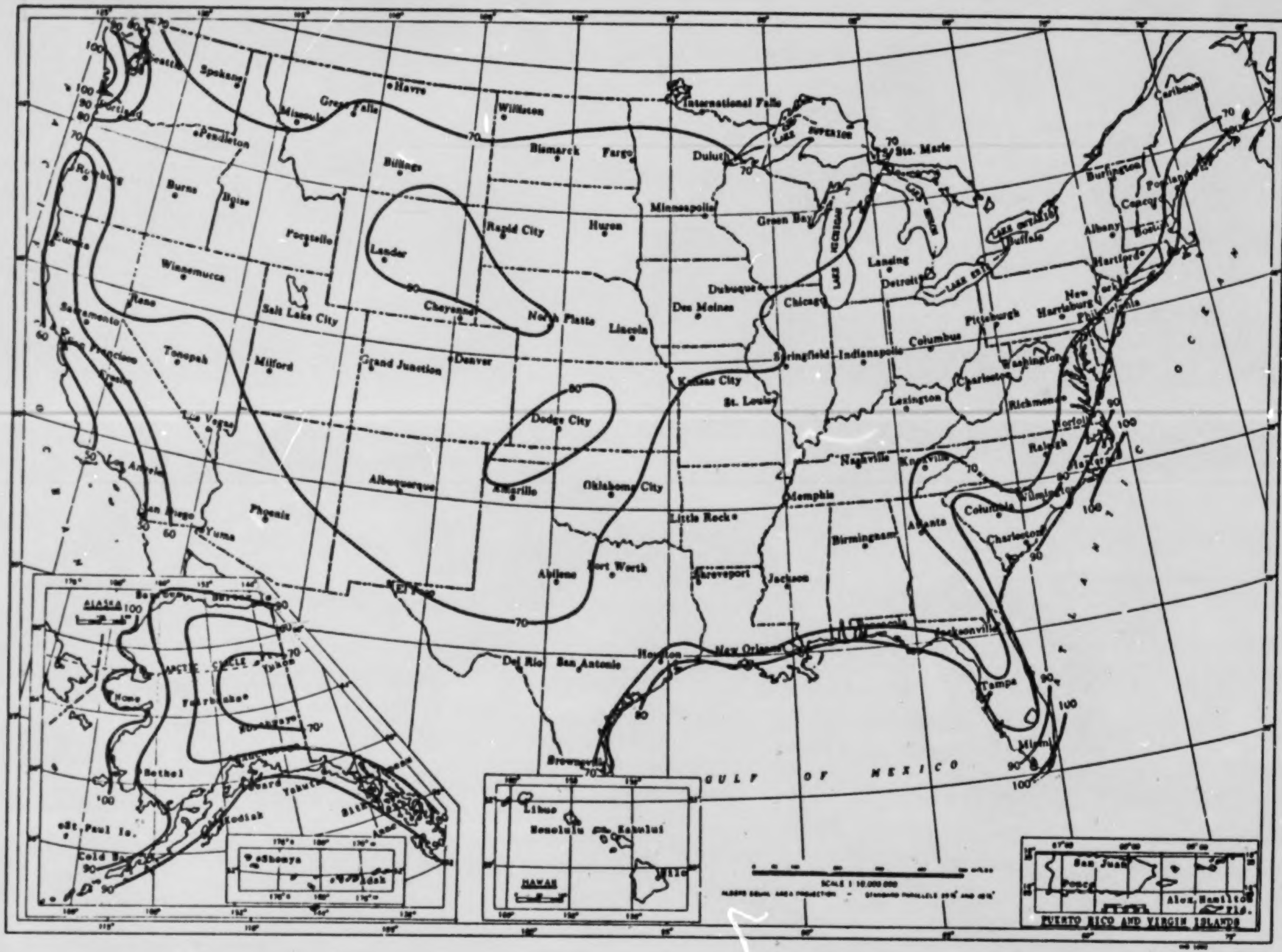
Williston
Bismarck
Fargo
International Falls
Duluth
Sault Ste. Marie
Caribou
Roseburg
Burns
Boise
Billings
Pocatello
Rapid City
Huron
Minneapolis
Green Bay
Burlington
Concord
Portland
Boston
Albany
Buffalo
Eureka
Winnemucca
Lander
Reno
Salt Lake City
Cheyenne
North Platte
Lincoln
Des Moines
Dubuque
Chicago
Lansing
Detroit
Hartford
New York
Philadelphia
Harrisburg
Pittsburgh
Sacramento
San Francisco
Tonopah
Milford
Grand Junction
Denver
Fresno
Kansas City
St. Louis
Springfield
Indianapolis
Columbus
Washington
Charleston
Lexington
Richmond
Norfolk
Las Vegas
Dodge City
Los Angeles
San Diego
Yuma
Phoenix
Albuquerque
Amarillo
Oklahoma City
Little Rock
Memphis
Nashville
Knoxville
Raleigh
Hatteras
Wilmington
Columbia
Atlanta
Birmingham
Charleston
El Paso
Abilene
Fort Worth
Shreveport
Jackson
Pensacola
Jacksonville
Del Rio
San Antonio
Houston
New Orleans
Tampa
Miami
Brownsville
GULF OF MEXICO
ALASKA
Barrow
Fairbanks
Nome
Bethel
Anchorage
Kodiak
Yakutat
Sitka
Juneau
Annette
St. Paul Is.
Cold Bay
HAWAII
Lihue
Honolulu
Kahului
Hilo
PUERTO RICO AND VIRGIN ISLANDS
San Juan
Ponce
SCALE 1:10,000,000
ALBERS EQUAL AREA PROJECTION - STANDARD PARALLELS 29½° AND 45½°
50
60
70
80
90

Fig. 21 Isotach 0.10 quantiles, in miles per hour: annual extreme-mile
30 feet above ground, 10-year mean recurrence interval (after Thom)



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Havre
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Missoula
Williston
Pendleton
Bismarck
Fargo
Duluth
International Falls
LAKE SUPERIOR
Sault Ste. Marie
Roseburg
Burns
Boise
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Kodiak
Sitka
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St. Paul Is.
Cold Bay
Shemya
Adak
Lihue
Honolulu
Kahului
Hilo
HAWAII
San Juan
Ponce
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS
SCALE 1:10,000,000
ALBERS EQUAL AREA PROJECTION - STANDARD PARALLELS 29½° AND 45½°

Fig. 22 Isotach 0.04 quantiles, in miles per hour: annual extreme-mile 30 feet above ground, 25-year mean recurrence interval (after Thom)

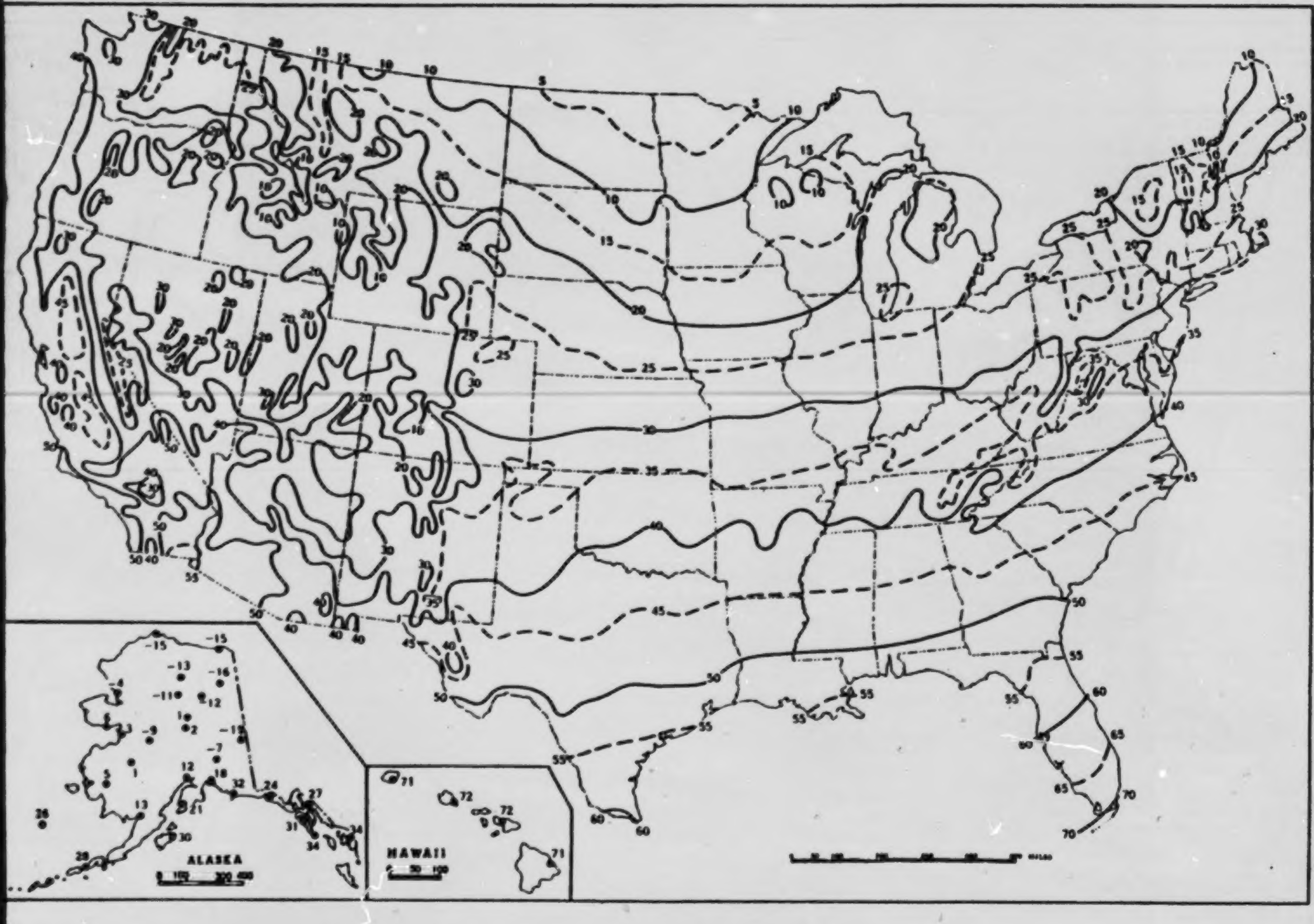
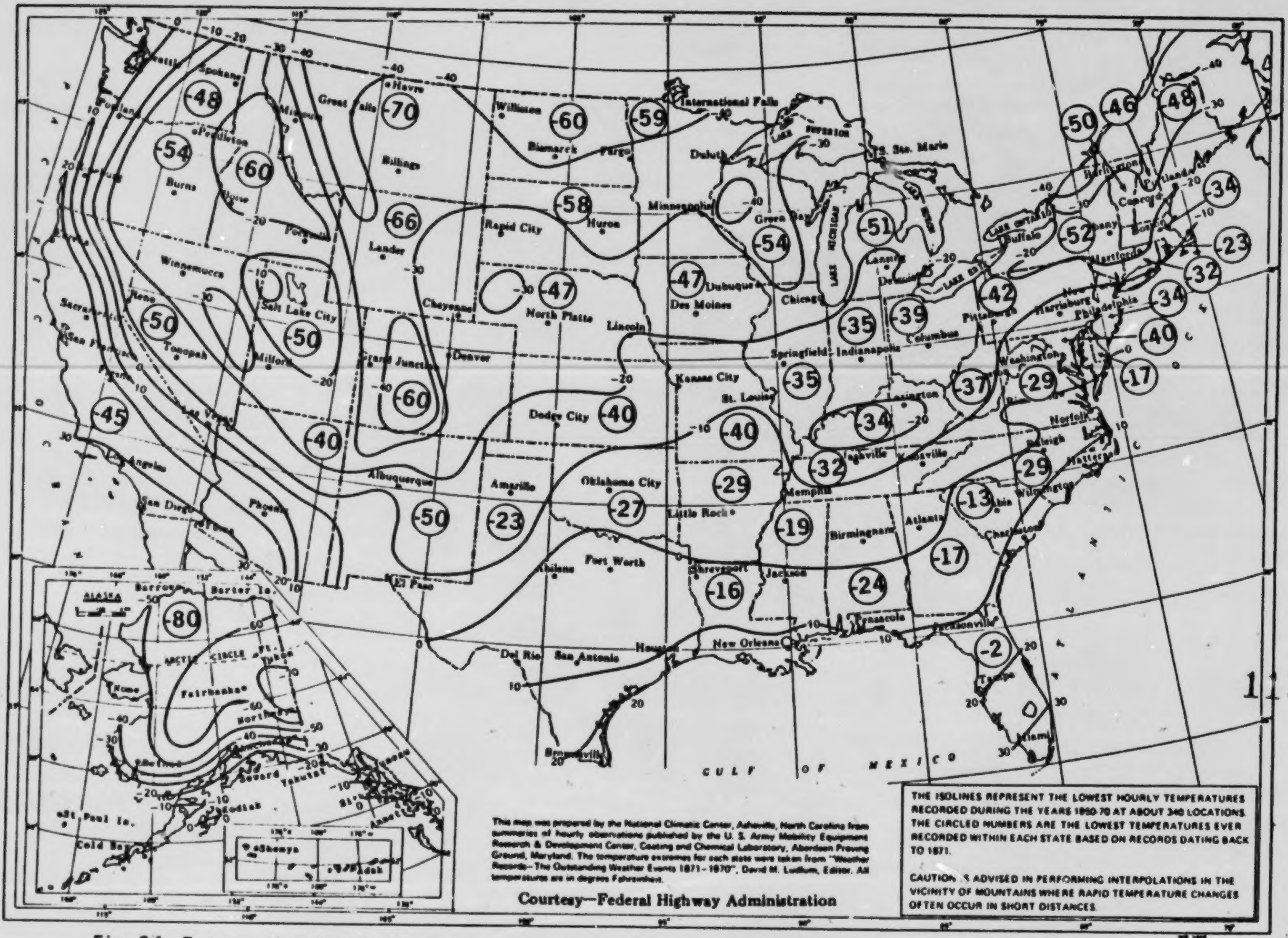

ALASKA
HAWAII

Fig. 23 Normal daily average temperature (°F) for January (1941–70)


ALASKA
Barrow
Barter Is.
-80
Arctic Circle
Ft. Yukon
Nome
Fairbanks
Northway
Bethel
Seward
Yakutat
Kodiak
St. Paul Is.
Cold Bay
Shemya
Adak
Juneau
Annette
GULF OF MEXICO
Seattle
Spokane
Portland
Pendleton
Burns
Boise
Pocatello
Missoula
Great Falls
Havre
Billings
Lander
Williston
Bismarck
Fargo
International Falls
Duluth
Minneapolis
Huron
Rapid City
Green Bay
Sault Ste. Marie
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Lansing
Detroit
Buffalo
Albany
Burlington
Concord
Portland
Boston
Hartford
New York
Harrisburg
Philadelphia
Pittsburgh
Washington
Richmond
Norfolk
Raleigh
Hatteras
Wilmington
Columbia
Charleston
Atlanta
Birmingham
Knoxville
Nashville
Lexington
Columbus
Indianapolis
Springfield
Chicago
Dubuque
Des Moines
Lincoln
North Platte
Cheyenne
Denver
Grand Junction
Salt Lake City
Milford
Winnemucca
Reno
Sacramento
San Francisco
Fresno
Tonopah
Las Vegas
Los Angeles
San Diego
Yuma
Phoenix
Albuquerque
El Paso
Amarillo
Dodge City
Kansas City
St. Louis
Oklahoma City
Little Rock
Memphis
Abilene
Fort Worth
Shreveport
Jackson
Del Rio
San Antonio
Houston
New Orleans
Pensacola
Jacksonville
Tampa
Miami
Brownsville
-48
-54
-60
-70
-66
-60
-59
-58
-50
-50
-47
-47
-60
-45
-40
-40
-50
-23
-27
-40
-29
-54
-51
-35
-35
-39
-42
-50
-46
-48
-34
-52
-23
-32
-34
-40
-17
-37
-29
-34
-32
-29
-13
-19
-16
-24
-17
-2

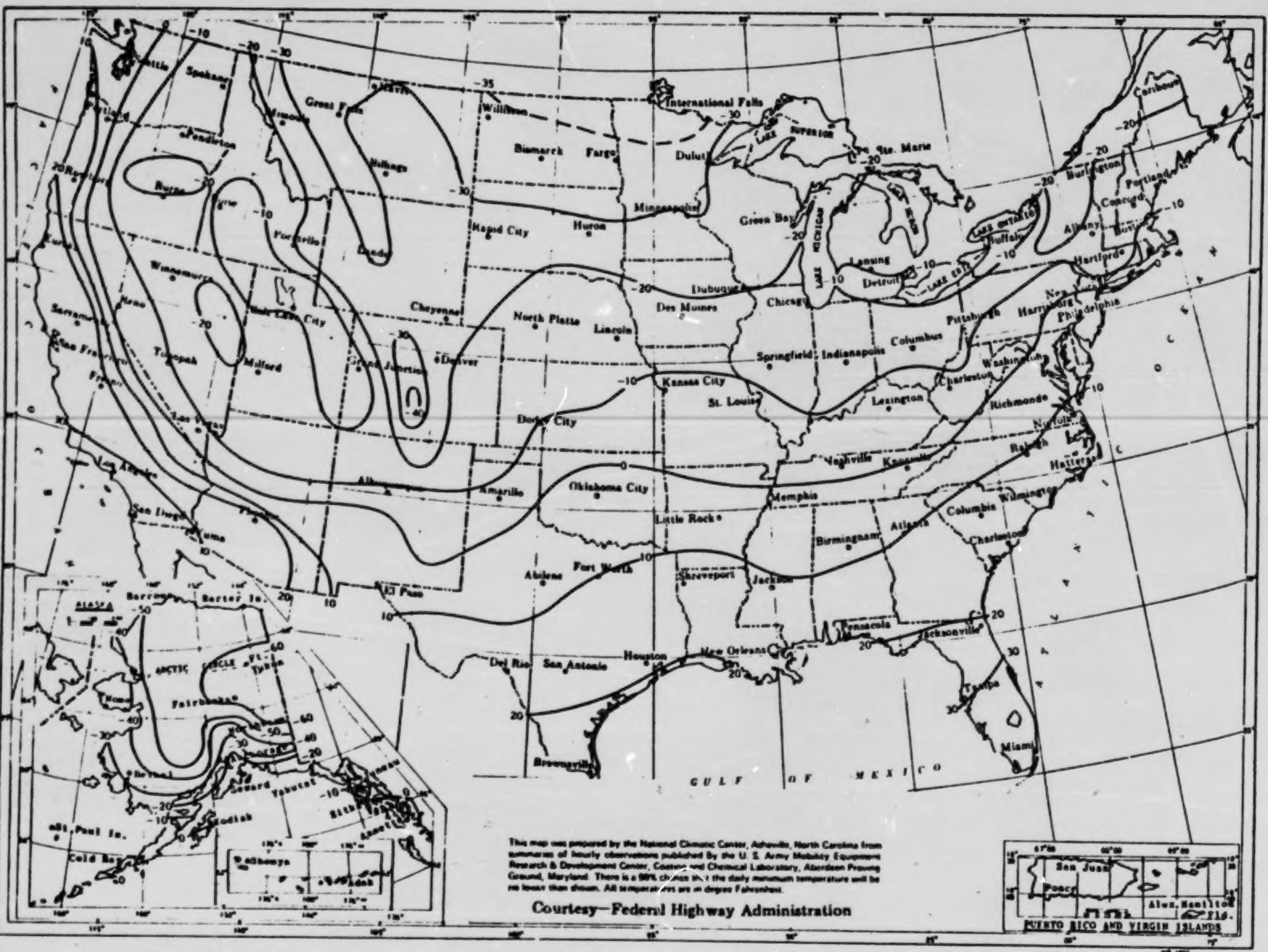
This map was prepared by the National Climatic Center, Asheville, North Carolina from summaries of hourly observations published by the U. S. Army Mobility Equipment Research & Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland. The temperature extremes for each state were taken from "Weather Records—The Outstanding Weather Events 1871-1970", David M. Ludlum, Editor. All temperatures are in degrees Fahrenheit.

Courtesy—Federal Highway Administration

THE ISOLINES REPRESENT THE LOWEST HOURLY TEMPERATURES RECORDED DURING THE YEARS 1950-70 AT ABOUT 340 LOCATIONS. THE CIRCLED NUMBERS ARE THE LOWEST TEMPERATURES EVER RECORDED WITHIN EACH STATE BASED ON RECORDS DATING BACK TO 1871.

CAUTION IS ADVISED IN PERFORMING INTERPOLATIONS IN THE VICINITY OF MOUNTAINS WHERE RAPID TEMPERATURE CHANGES OFTEN OCCUR IN SHORT DISTANCES.

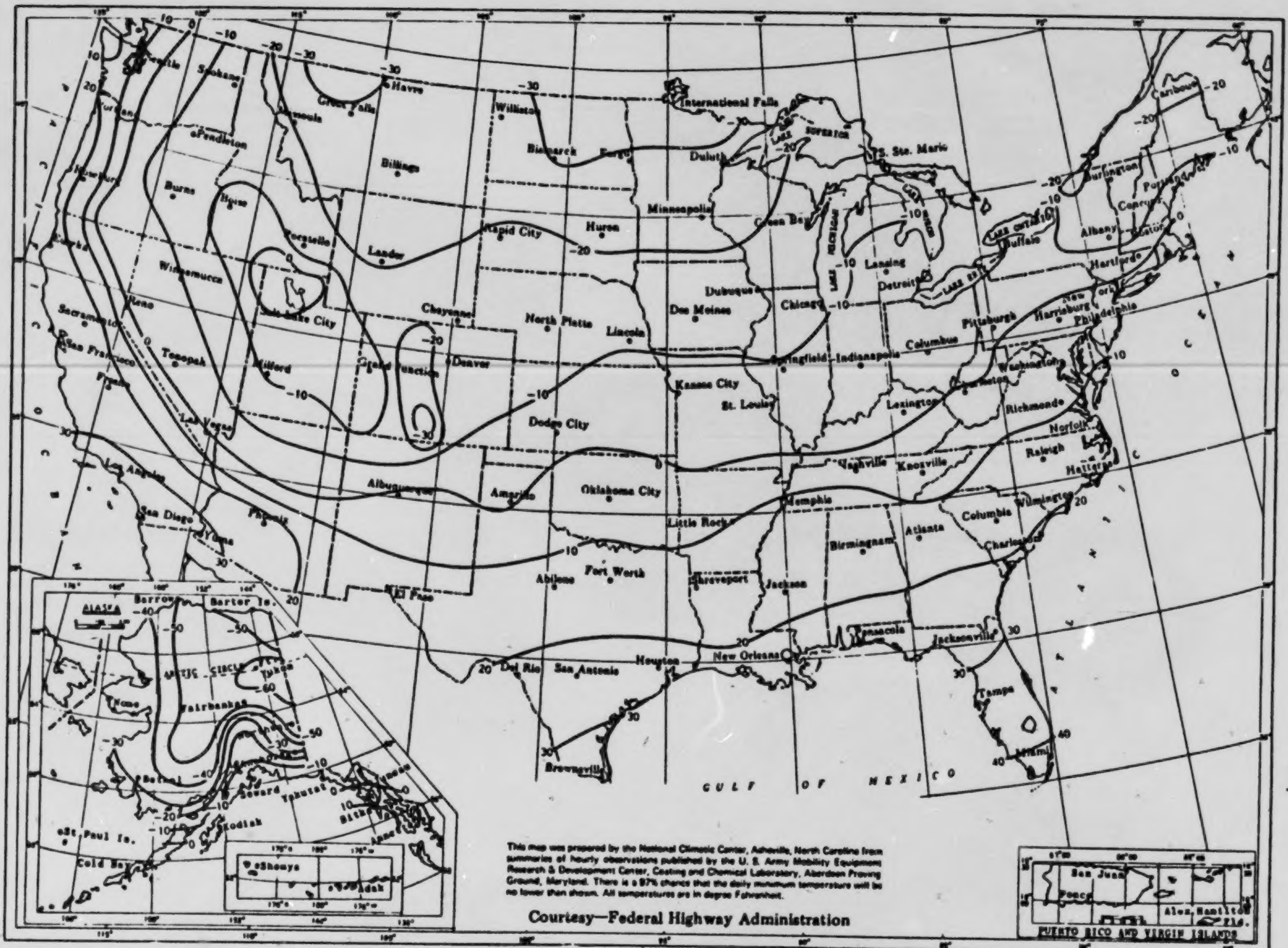
Fig. 24 Extreme low hourly temperatures during the winter season with absolute minimums for each state


Seattle
Spokane
Portland
Pendleton
Great Falls
Havre
Missoula
Billings
Williston
Bismarck
Fargo
International Falls
Lake Superior
Duluth
Ste. Marie
Caribou
Burlington
Portland
Concord
Albany
Boston
Hartford
Lake Ontario
Buffalo
Lake Erie
Lake Michigan
Lake Huron
Green Bay
Minneapolis
Huron
Rapid City
Burns
Boise
Pocatello
Lander
Winnemucca
Reno
Sacramento
San Francisco
Fresno
Tonopah
Salt Lake City
Milford
Grand Junction
Denver
Cheyenne
North Platte
Lincoln
Des Moines
Dubuque
Chicago
Lansing
Detroit
Pittsburgh
Harrisburg
New York
Philadelphia
Springfield
Indianapolis
Columbus
Washington
Charleston
Kansas City
St. Louis
Lexington
Richmond
Norfolk
Dodge City
Las Vegas
Los Angeles
San Diego
Yuma
Phoenix
Albuquerque
Amarillo
Oklahoma City
Nashville
Knoxville
Raleigh
Hatteras
Memphis
Little Rock
Birmingham
Atlanta
Columbia
Wilmington
Charleston
Abilene
Fort Worth
Shreveport
Jackson
El Paso
Del Rio
San Antonio
Houston
New Orleans
Pensacola
Jacksonville
Tampa
Miami
Brownsville
GULF OF MEXICO
-35
-30
-20
-10
0
10
20
30
-40
ALASKA
Barrow
Barter Is.
ARCTIC CIRCLE
Ft. Yukon
Fairbanks
Nome
Bethel
Seward
Yakutat
Sitka
Juneau
Annette
Kodiak
St. Paul Is.
Cold Bay
-50
-60
San Juan
Ponce
PUERTO RICO AND VIRGIN ISLANDS

This map was prepared by the National Climatic Center, Asheville, North Carolina from summaries of hourly observations published by the U. S. Army Mobility Equipment Research & Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland. There is a 99% chance that the daily minimum temperature will be no lower than shown. All temperatures are in degrees Fahrenheit.

Courtesy—Federal Highway Administration

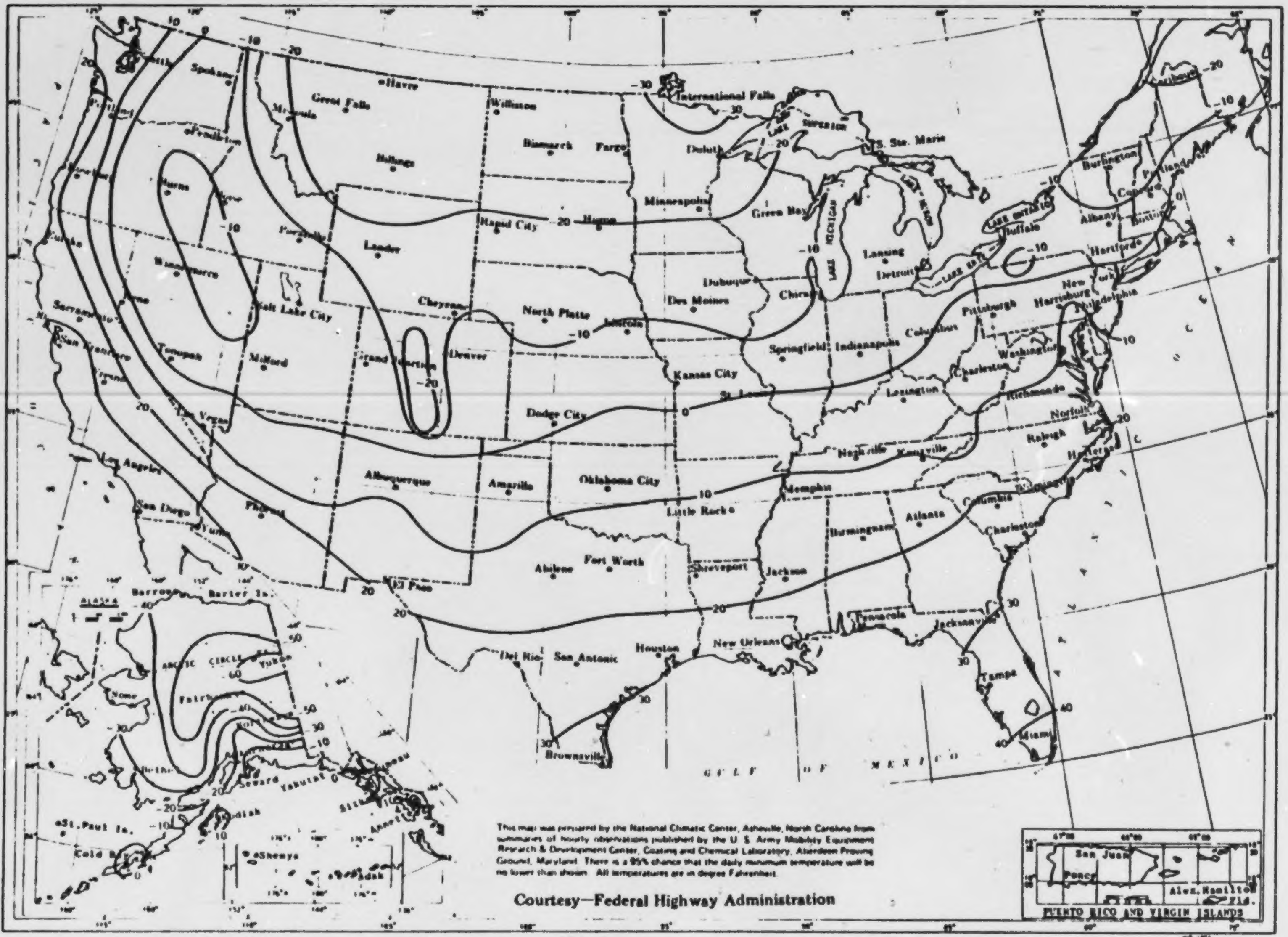
Fig. 25 Minimum temperatures colder than indicated 1% of the hours during the winter season


Seattle
Spokane
Havre
Great Falls
Missoula
Portland
Pendleton
Billings
Williston
Bismarck
Fargo
International Falls
Duluth
LAKE SUPERIOR
S. Ste. Marie
Caribou
Burlington
Portland
Concord
Albany
Boston
Burns
Boise
Pocatello
Lander
Rapid City
Huron
Minneapolis
Green Bay
LAKE MICHIGAN
LAKE HURON
Lansing
Detroit
LAKE ONTARIO
Buffalo
Hartford
New York
Medford
Eureka
Winnemucca
Reno
Salt Lake City
Cheyenne
North Platte
Lincoln
Des Moines
Dubuque
Chicago
LAKE ERIE
Pittsburgh
Harrisburg
Philadelphia
Sacramento
San Francisco
Tonopah
Milford
Grand Junction
Denver
Springfield
Indianapolis
Columbus
Washington
Fresno
Las Vegas
Dodge City
Kansas City
St. Louis
Lexington
Charleston
Richmond
Norfolk
Raleigh
Hatteras
Nashville
Knoxville
Los Angeles
San Diego
Yuma
Phoenix
Albuquerque
Amarillo
Oklahoma City
Memphis
Little Rock
Columbia
Wilmington
Atlanta
Birmingham
Charleston
Abilene
Fort Worth
Shreveport
Jackson
El Paso
Pensacola
Jacksonville
Del Rio
San Antonio
Houston
New Orleans
Tampa
Miami
Brownsville
GULF OF MEXICO
ALASKA
Barrow
Barter Is.
ARCTIC CIRCLE
Yukon
Nome
Fairbanks
Bethel
Seward
Yakutat
Kodiak
Sitka
Juneau
Annette
St. Paul Is.
Cold Bay
Shemya
Adak
San Juan
Ponce
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS
-50
-40
-30
-20
-10
0
10
20
30
40

This map was prepared by the National Climatic Center, Asheville, North Carolina from summaries of hourly observations published by the U. S. Army Mobility Equipment Research & Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland. There is a 97% chance that the daily minimum temperature will be no lower than shown. All temperatures are in degree Fahrenheit.

Courtesy—Federal Highway Administration

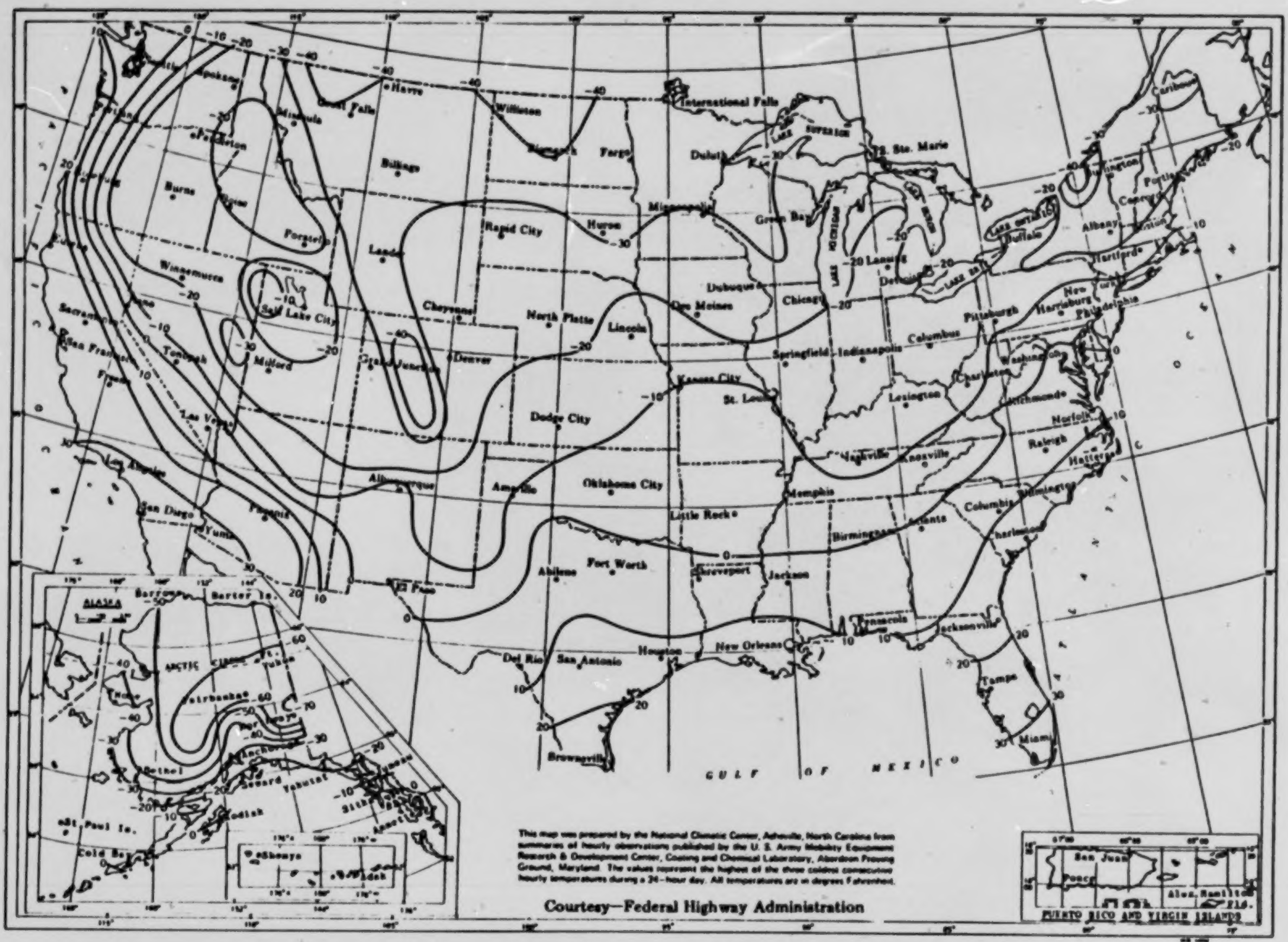
Fig. 26 Minimum temperatures colder than indicated 3% of the hours during the winter season


Seattle
Spokane
Portland
Pendleton
Burns
Boise
Pocatello
Eureka
Winnemucca
Sacramento
San Francisco
Fresno
Reno
Tonopah
Milford
Salt Lake City
Las Vegas
Los Angeles
San Diego
Yuma
Phoenix
Havre
Great Falls
Missoula
Billings
Lander
Cheyenne
Grand Junction
Denver
Albuquerque
El Paso
Williston
Bismarck
Fargo
Rapid City
Huron
North Platte
Lincoln
Dodge City
Amarillo
Oklahoma City
Abilene
Fort Worth
Del Rio
San Antonio
Houston
Brownsville
International Falls
Duluth
Minneapolis
Des Moines
Dubuque
Kansas City
St. Louis
Little Rock
Shreveport
Memphis
Jackson
New Orleans
Green Bay
Chicago
Springfield
Indianapolis
Lansing
Detroit
Sault Ste. Marie
Columbus
Lexington
Nashville
Knoxville
Birmingham
Atlanta
Pensacola
Jacksonville
Tampa
Miami
Columbia
Charleston
Wilmington
Raleigh
Hatteras
Norfolk
Richmond
Washington
Charleston
Pittsburgh
Harrisburg
Philadelphia
New York
Hartford
Buffalo
Albany
Burlington
Concord
Portland
Boston
Caribou
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
GULF OF MEXICO
-30
-20
-10
0
10
20
30
40
ALASKA
Barrow
Barter Is.
ARCTIC CIRCLE
Yukon
Nome
Fairbanks
Bethel
Seward
Yakutat
Sitka
Annette
Kodiak
St. Paul Is.
Cold Bay
Shemya
Adak
-50
-40
-30
-20
-10
0
10
San Juan
Ponce
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS

This map was prepared by the National Climatic Center, Asheville, North Carolina from summaries of hourly observations published by the U. S. Army Mobility Equipment Research & Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland. There is a 95% chance that the daily minimum temperature will be no lower than shown. All temperatures are in degree Fahrenheit.

Courtesy—Federal Highway Administration

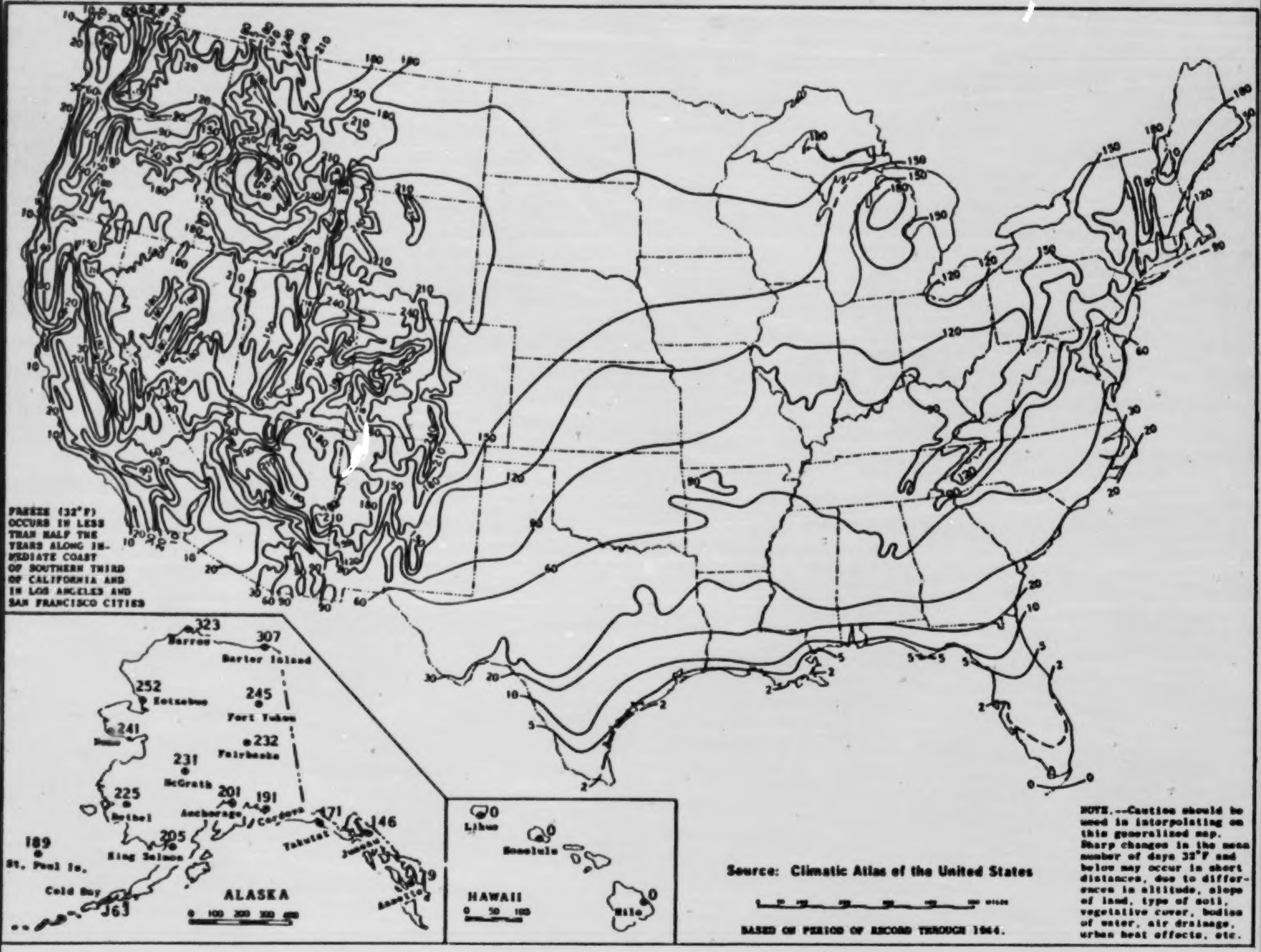
Fig. 27 Minimum temperatures colder than indicated 5% of the hours during the winter season


Seattle
Spokane
Havre
Great Falls
Williston
International Falls
Portland
Pendleton
Missoula
Billings
Bismarck
Fargo
Duluth
Lake Superior
Sault Ste. Marie
Caribou
Burlington
Portland
Concord
Albany
Boston
Hartford
New York
Lake Ontario
Buffalo
Lake Erie
Detroit
Lansing
Lake Huron
Lake Michigan
Green Bay
Minneapolis
Huron
Rapid City
Lander
Pocatello
Boise
Burns
Eureka
Red Bluff
Winnemucca
Reno
Sacramento
San Francisco
Fresno
Tonopah
Salt Lake City
Milford
Grand Junction
Denver
Cheyenne
North Platte
Lincoln
Des Moines
Dubuque
Chicago
Springfield
Indianapolis
Columbus
Pittsburgh
Harrisburg
Philadelphia
Washington
Charleston
Richmond
Norfolk
Raleigh
Hatteras
Lexington
Knoxville
Nashville
St. Louis
Kansas City
Dodge City
Las Vegas
Los Angeles
San Diego
Yuma
Phoenix
Albuquerque
Amarillo
Oklahoma City
Little Rock
Memphis
Birmingham
Atlanta
Columbia
Wilmington
Charleston
El Paso
Abilene
Fort Worth
Shreveport
Jackson
Pensacola
Jacksonville
Tampa
Miami
New Orleans
Houston
San Antonio
Del Rio
Brownsville
GULF OF MEXICO
-40
-30
-20
-10
0
10
20
30
ALASKA
Barrow
Barter Is.
ARCTIC CIRCLE
Ft. Yukon
Fairbanks
Nome
Bethel
Anchorage
Seward
Yakutat
Juneau
Sitka
Annette
Kodiak
St. Paul Is.
Cold Bay
Shemya
Adak
San Juan
Ponce
Alex. Hamilton Fld.
PUERTO RICO AND VIRGIN ISLANDS

This map was prepared by the National Climatic Center, Asheville, North Carolina from summaries of hourly observations published by the U. S. Army Mobility Equipment Research & Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland. The values represent the highest of the three coldest consecutive hourly temperatures during a 24-hour day. All temperatures are in degrees Fahrenheit.

Courtesy—Federal Highway Administration

Fig. 28 Consecutive 3—hour minimum temperature during the winter season


ALASKA
323 Barrow
307 Barter Island
252 Kotzebue
245 Fort Yukon
241 Nome
232 Fairbanks
231 McGrath
225 Bethel
201 Anchorage
191 Cordova
171 Yakutat
146 Juneau
205 King Salmon
189 St. Paul Is.
163 Cold Bay
Annette
HAWAII
0 Lihue
0 Honolulu
0 Hilo

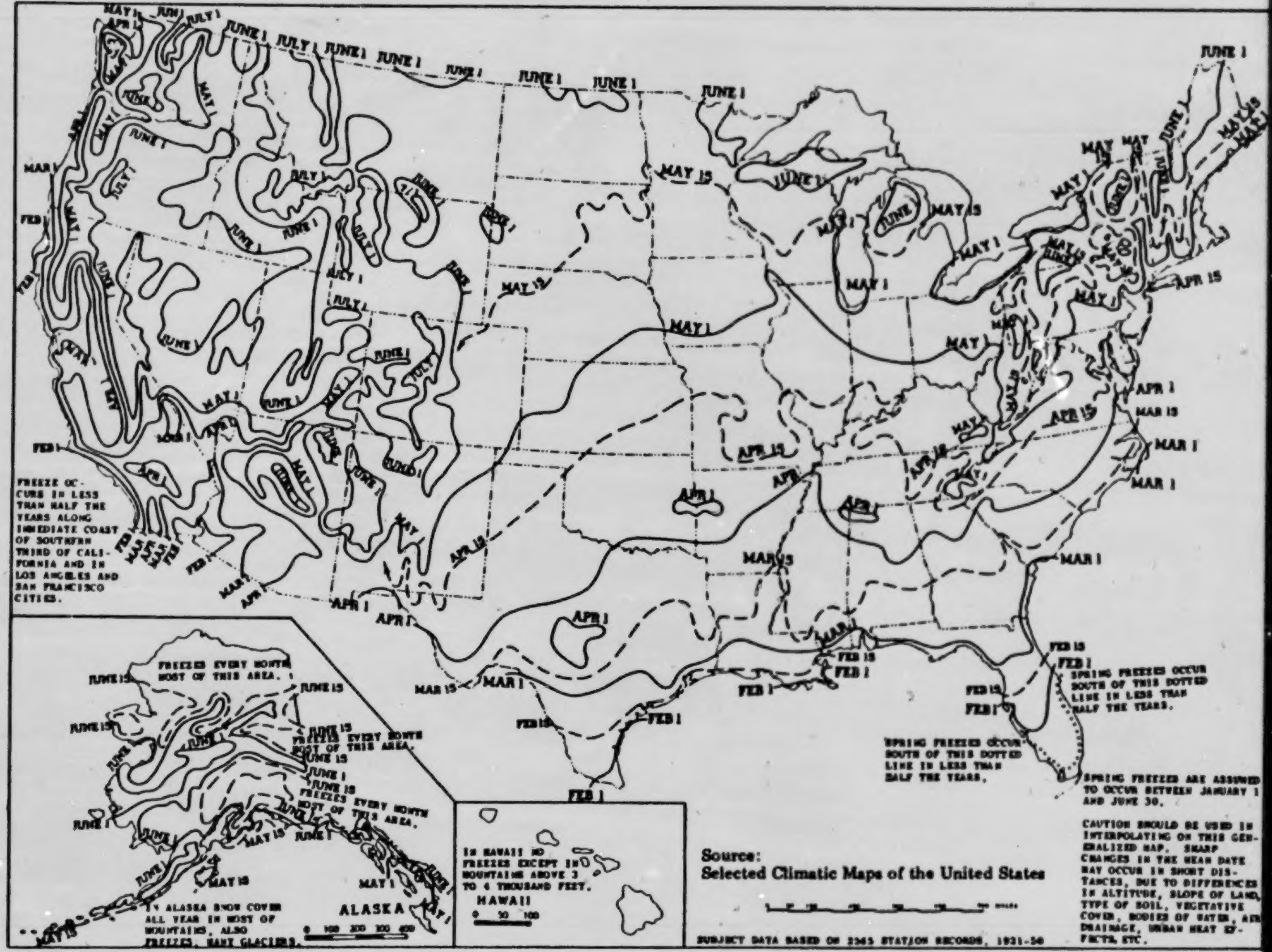
FREEZE (32°F) OCCURS IN LESS THAN HALF THE YEARS ALONG IMMEDIATE COAST OF SOUTHERN THIRD OF CALIFORNIA AND IN LOS ANGELES AND SAN FRANCISCO CITIES

Source: Climatic Atlas of the United States

BASED ON PERIOD OF RECORD THROUGH 1964.

NOTE.--Caution should be used in interpolating on this generalized map. Sharp changes in the mean number of days 32°F and below may occur in short distances, due to differences in altitude, slope of land, type of soil, vegetative cover, bodies of water, air drainage, urban heat effects, etc.

Fig. 29 Mean annual number of days minimum temperature 32°F and below

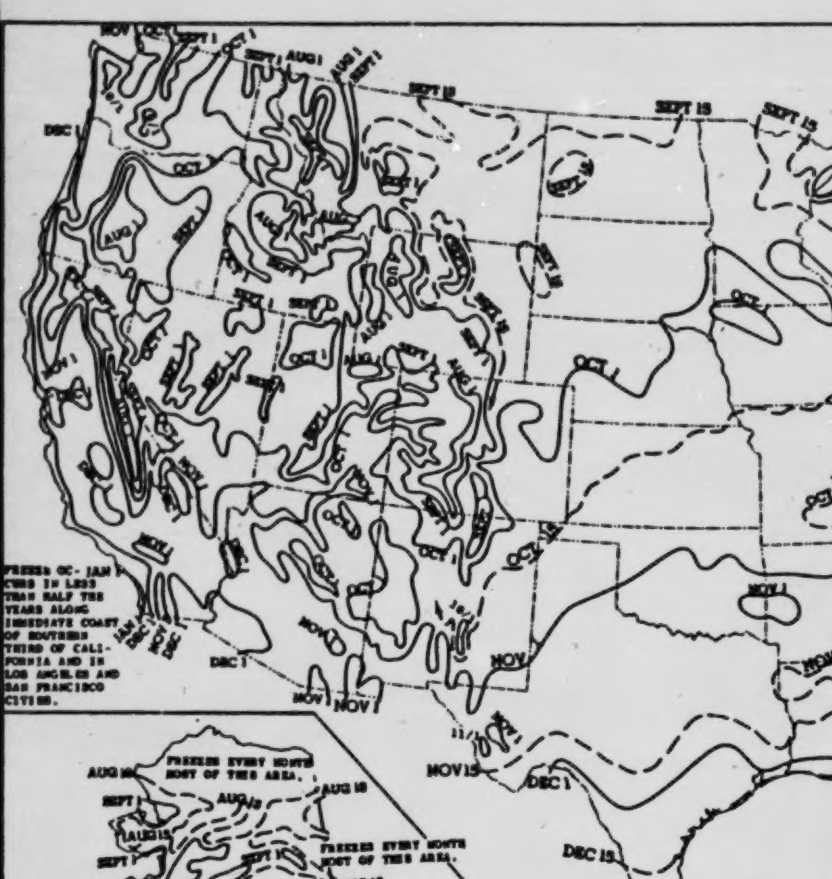


JUNE 1
JULY 1
MAY 15
MAY 1
APR 15
APR 1
MAR 15
MAR 1
FEB 15
FEB 1
FREEZE OCCURS IN LESS THAN HALF THE YEARS ALONG IMMEDIATE COAST OF SOUTHERN THIRD OF CALIFORNIA AND IN LOS ANGELES AND SAN FRANCISCO CITIES.
SPRING FREEZES OCCUR SOUTH OF THIS DOTTED LINE IN LESS THAN HALF THE YEARS.
SPRING FREEZES OCCUR SOUTH OF THIS DOTTED LINE IN LESS THAN HALF THE YEARS.
SPRING FREEZES ARE ASSUMED TO OCCUR BETWEEN JANUARY 1 AND JUNE 30.
CAUTION SHOULD BE USED IN INTERPOLATING ON THIS GENERALIZED MAP. SHARP CHANGES IN THE MEAN DATE MAY OCCUR IN SHORT DISTANCES, DUE TO DIFFERENCES IN ALTITUDE, SLOPE OF LAND, TYPE OF SOIL, VEGETATIVE COVER, BODIES OF WATER, AIR DRAINAGE, URBAN HEAT EFFECTS, ETC.
FREEZES EVERY MONTH MOST OF THIS AREA.
FREEZES EVERY MONTH MOST OF THIS AREA.
FREEZES EVERY MONTH MOST OF THIS AREA.
IN ALASKA SNOW COVER ALL YEAR IN MOST OF MOUNTAINS, ALSO FREEZES, MANY GLACIERS.
ALASKA
0 100 200 300 400
IN HAWAII NO FREEZES EXCEPT IN MOUNTAINS ABOVE 3 TO 4 THOUSAND FEET.
HAWAII
0 50 100

Source:
Selected Climatic Maps of the United States

SUBJECT DATA BASED ON 2565 STATION RECORDS, 1931-50

Fig. 30 Mean date of last 32°F temperature in spring



FREEZES OC- JAN CURS IN LESS THAN HALF THE YEARS ALONG IMMEDIATE COAST OF SOUTHERN THIRD OF CALIFORNIA AND IN LOS ANGELES AND SAN FRANCISCO CITIES.

FREEZES EVERY MONTH MOST OF THIS AREA.

FREEZES EVERY MONTH MOST OF THIS AREA.

FREEZES EVERY MONTH MOST OF THIS AREA.

IN ALASKA SNOW COVER ALL YEAR IN MOST OF MOUNTAINS, ALSO FREEZES; MANY GLACIERS.

IN HAWAII NO FREEZES EXCEPT IN MOUNTAINS ABOVE 3 TO 6 THOUSAND FEET.

FALL FREEZES OCCUR SOUTH OF THIS DOTTED LINE IN LESS THAN HALF THE YEARS.

FALL FREEZES OCCUR SOUTH OF THIS DOTTED LINE IN LESS THAN HALF THE YEARS.

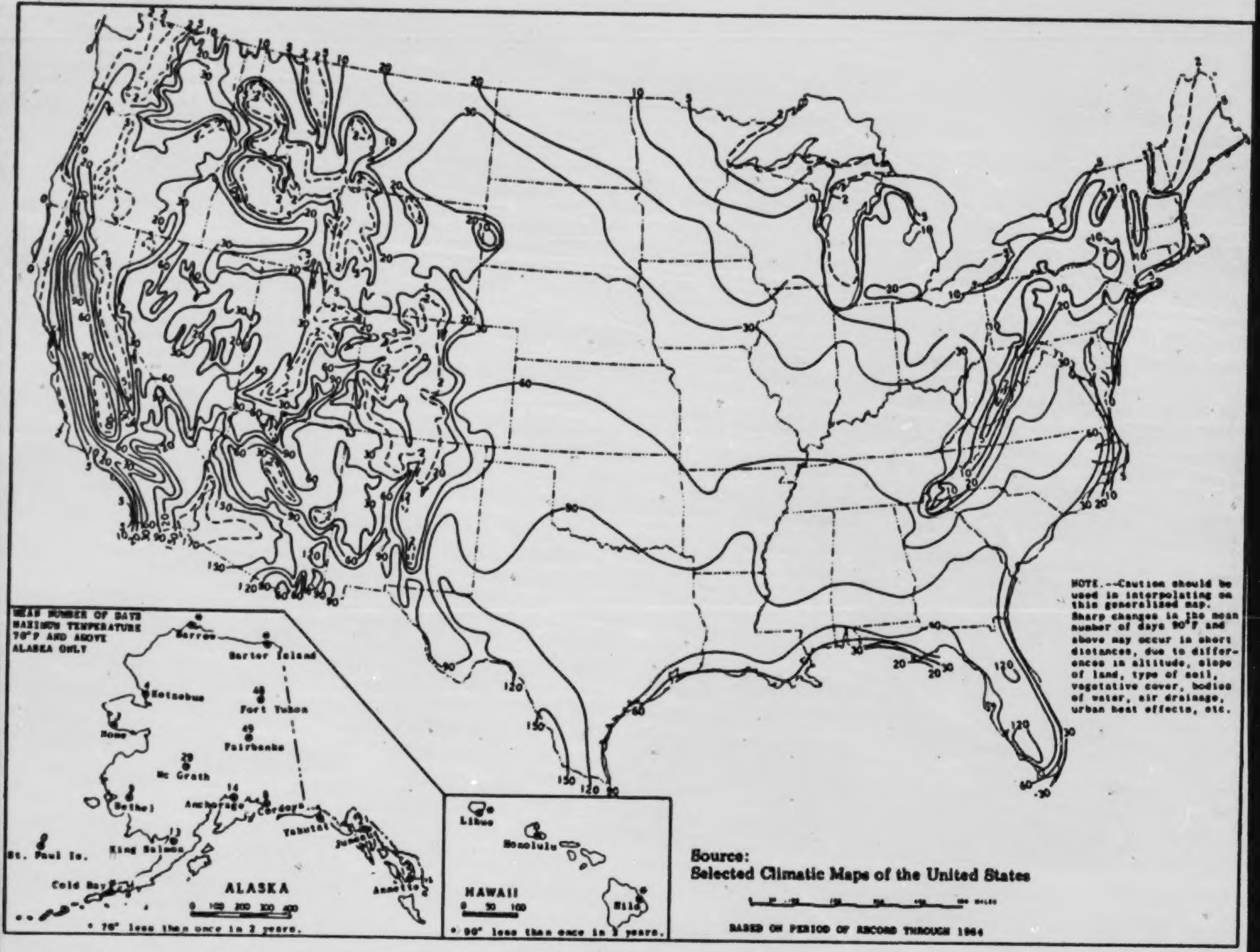
AUTUMN (FALL) FREEZES ARE ASSUMED TO OCCUR BETWEEN JULY 1 AND DECEMBER 31.

CAUTION SHOULD BE USED IN INTERPOLATING ON THIS GENERALIZED MAP. SHARP CHANGES IN THE MEAN DATE MAY OCCUR IN SHORT DISTANCES, DUE TO DIFFERENCES IN ALTITUDE, SLOPE OF LAND, TYPE OF SOIL, VEGETATIVE COVER, BODIES OF WATER, AIR DRAINAGE, URBAN HEAT EFFECTS, ETC.

Source:
Selected Climatic Maps of the United States

SUBJECT DATA BASED ON 3965 STATION RECORDS, 1931-50

Fig. 31 Mean date of first 32°F temperature in autumn

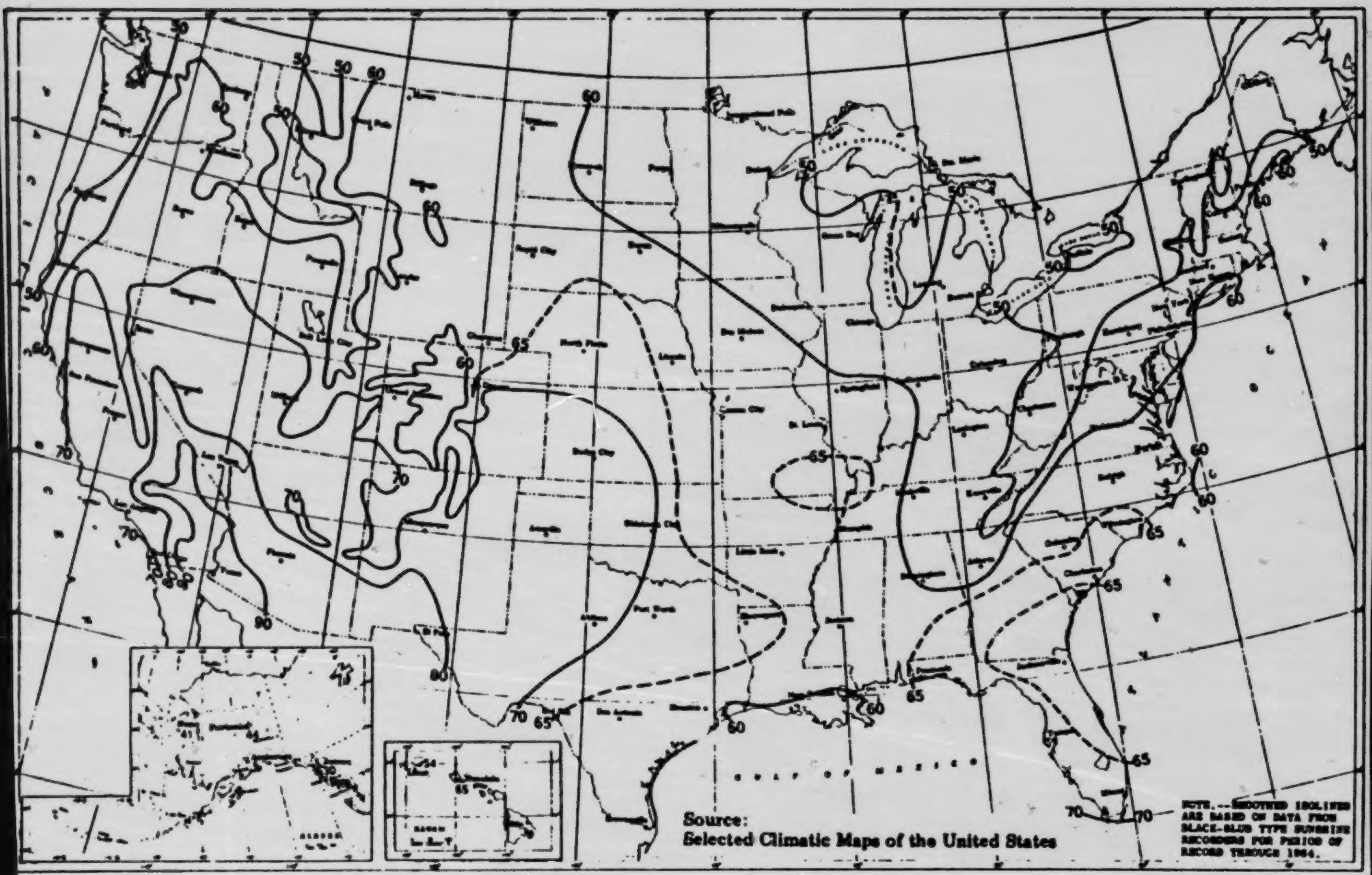

MEAN NUMBER OF DAYS MAXIMUM TEMPERATURE 70°F AND ABOVE ALASKA ONLY
Barrow
Barter Island
Kotzebue
Fort Yukon
Nome
Fairbanks
Mc Grath
Bethel
Anchorage
Cordova
Yakutat
Juneau
King Salmon
St. Paul Is.
Cold Bay
Annette
ALASKA
0 100 200 300 400
* 70° less than once in 2 years.
Lihue
Honolulu
Hilo
HAWAII
0 50 100
* 90° less than once in 2 years.

NOTE.--Caution should be used in interpolating on this generalized map. Sharp changes in the mean number of days 90°F and above may occur in short distances, due to differences in altitude, slope of land, type of soil, vegetative cover, bodies of water, air drainage, urban heat effects, etc.

Source:
Selected Climatic Maps of the United States

BASED ON PERIOD OF RECORD THROUGH 1964

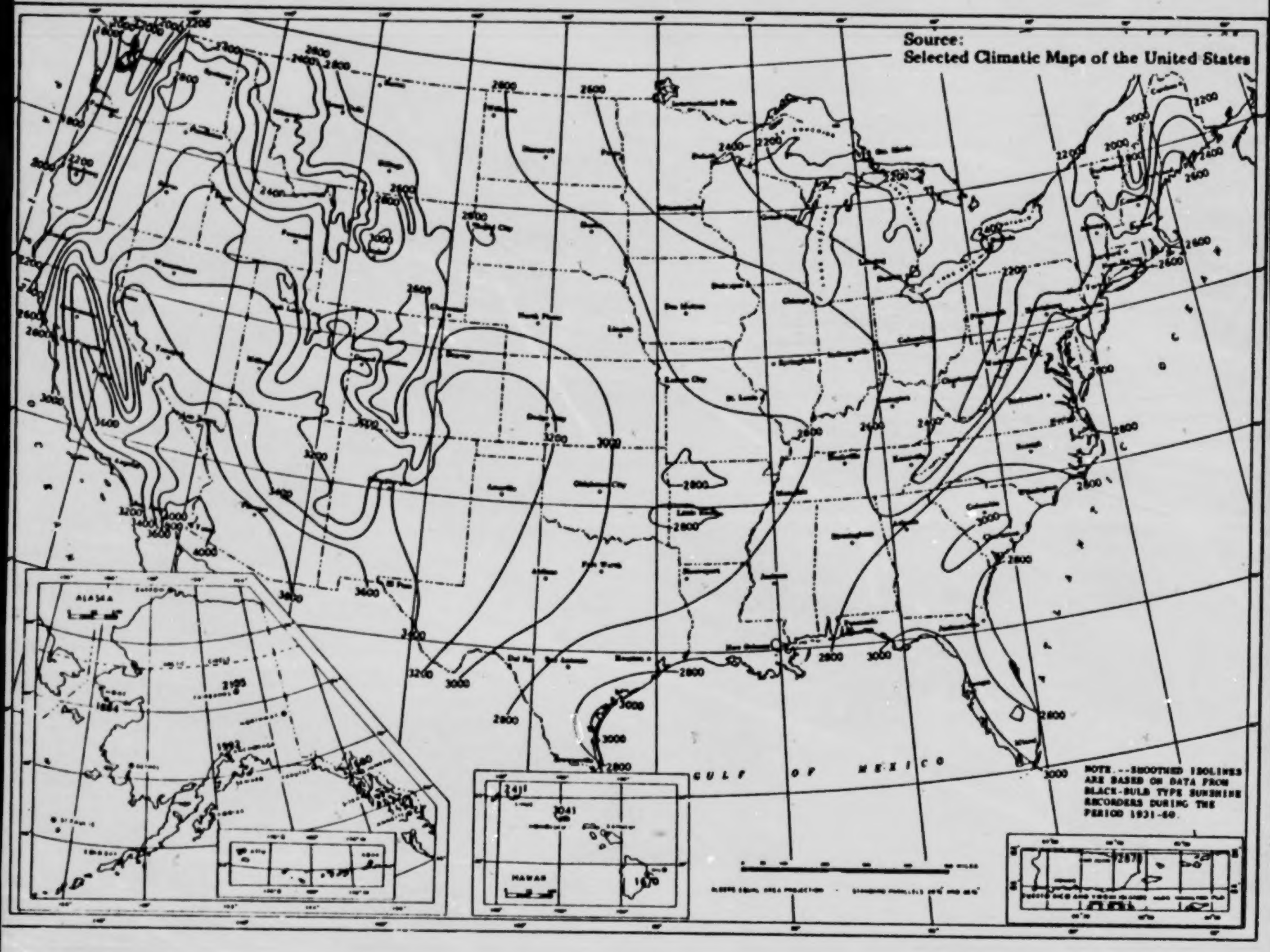
Fig. 32 Mean annual number of days maximum temperature 90°F and above except 70°F and above in Alaska


50
50
50
60
60
60
50
60
50
50
50
50
50
60
50
50
60
50
60
70
65
60
65
70
70
70
70
90
80
70
65
60
60
65
65
65
60
60
65
65
70
70
GULF OF MEXICO

Source:
Selected Climatic Maps of the United States

NOTE.--SMOOTHED ISOLINES ARE BASED ON DATA FROM BLACK-BULB TYPE SUNSHINE RECORDERS FOR PERIOD OF RECORD THROUGH 1964.

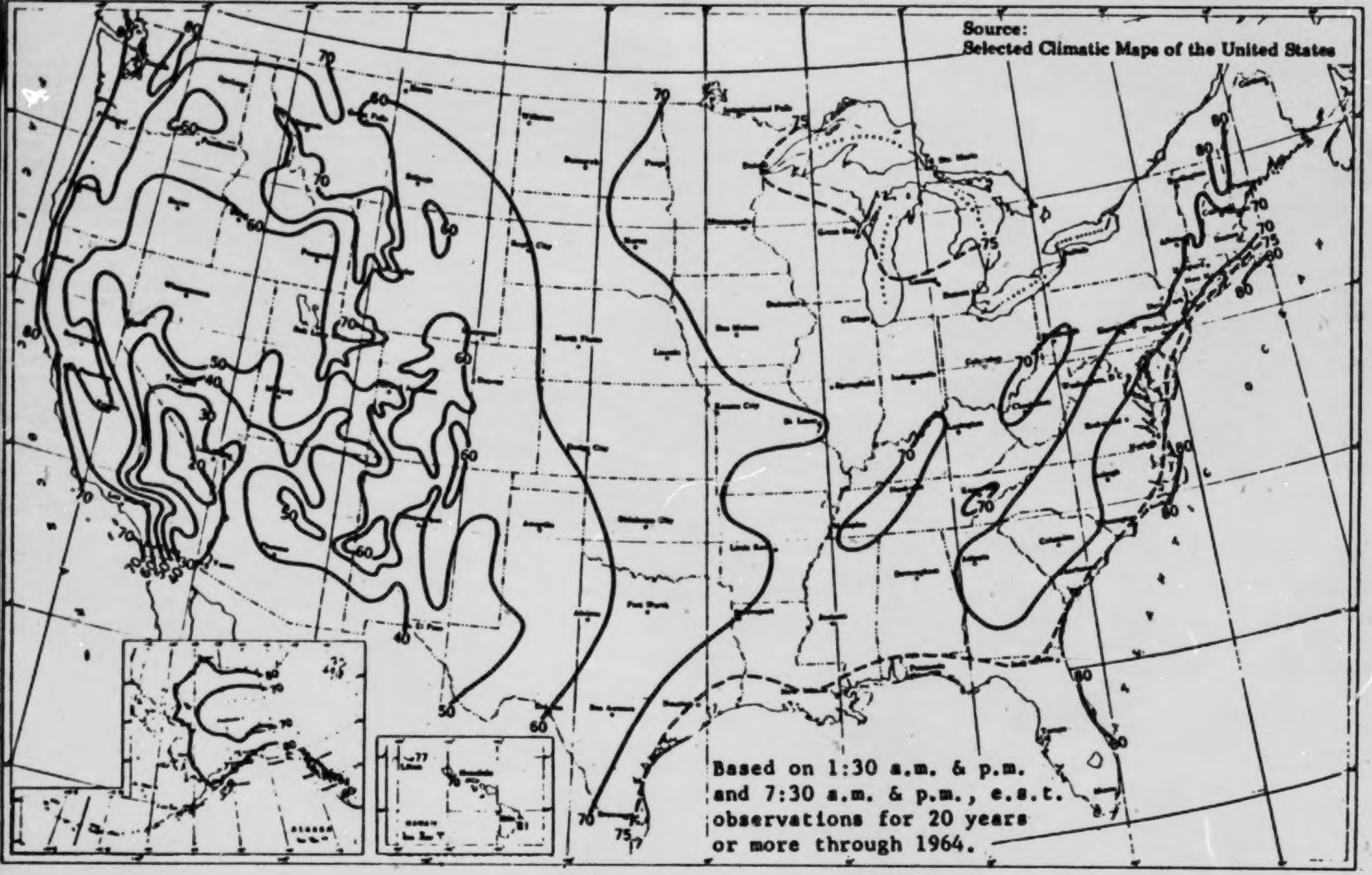
Fig. 33 Mean annual percentage of possible sunshine


ALASKA
HAWAII
GULF OF MEXICO
2200
2400
2600
2800
3000
3200
3400
3600
4000
2000
1800
2105
1884
2411
3041
1670
2671

Source:
Selected Climatic Maps of the United States

NOTE.--SMOOTHED ISOLINES ARE BASED ON DATA FROM BLACK-BULB TYPE SUNSHINE RECORDERS DURING THE PERIOD 1931-60.

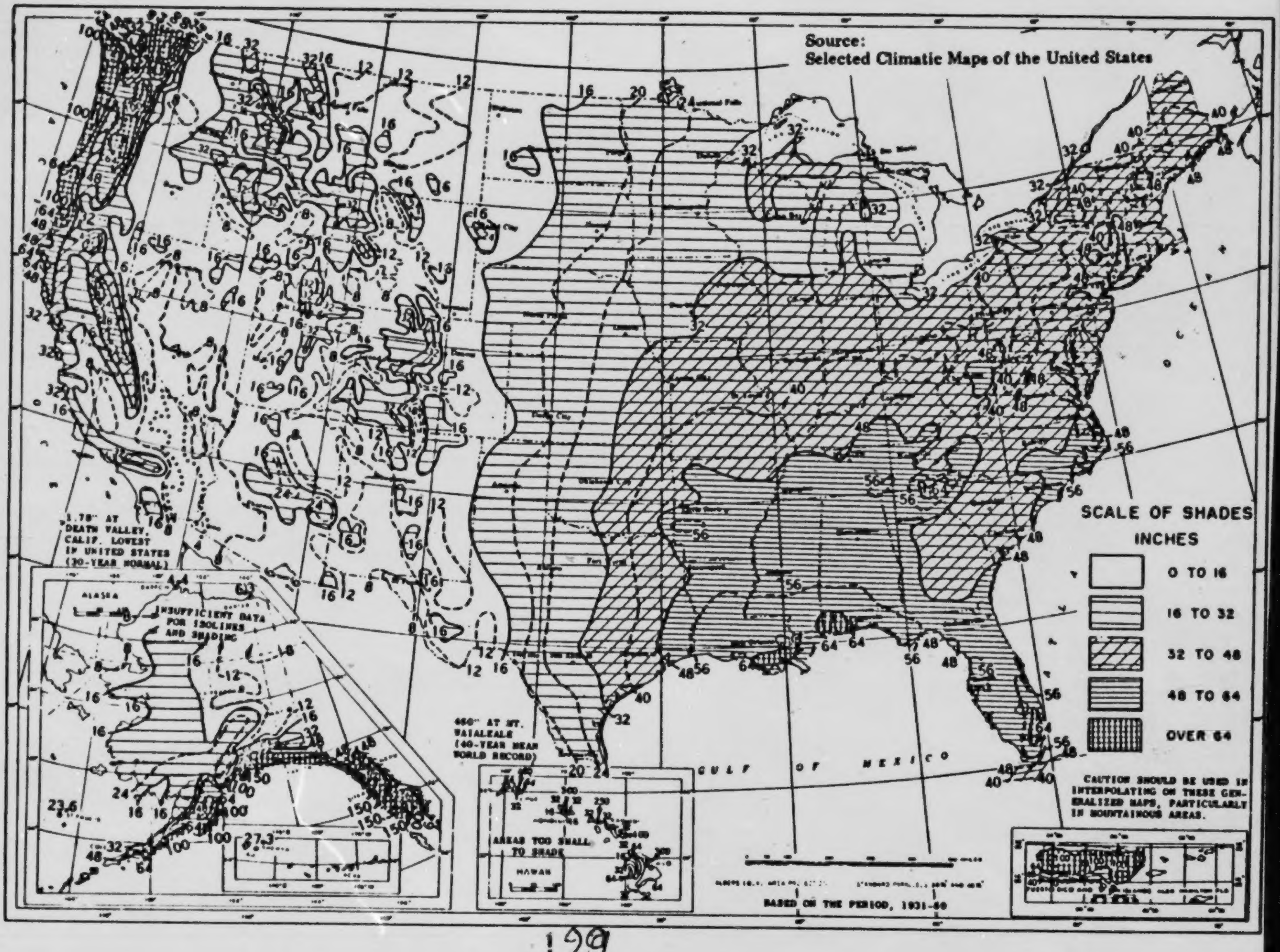
Fig. 34 Mean annual total hours of sunshine


80
70
60
50
40
30
20
75

Source:
Selected Climatic Maps of the United States

Based on 1:30 a.m. & p.m.
and 7:30 a.m. & p.m., e.s.t.
observations for 20 years
or more through 1964.

Fig. 35 Mean annual relative humidity (%)


SCALE OF SHADES
INCHES
0 TO 16
16 TO 32
32 TO 48
48 TO 64
OVER 64
GULF OF MEXICO
1.78" AT DEATH VALLEY, CALIF. LOWEST IN UNITED STATES (30-YEAR NORMAL)
ALASKA
INSUFFICIENT DATA FOR ISOLINES AND SHADING
460" AT MT. WAIALEALE (40-YEAR MEAN WORLD RECORD)
AREAS TOO SMALL TO SHADE
HAWAII
BASED ON THE PERIOD, 1931-60

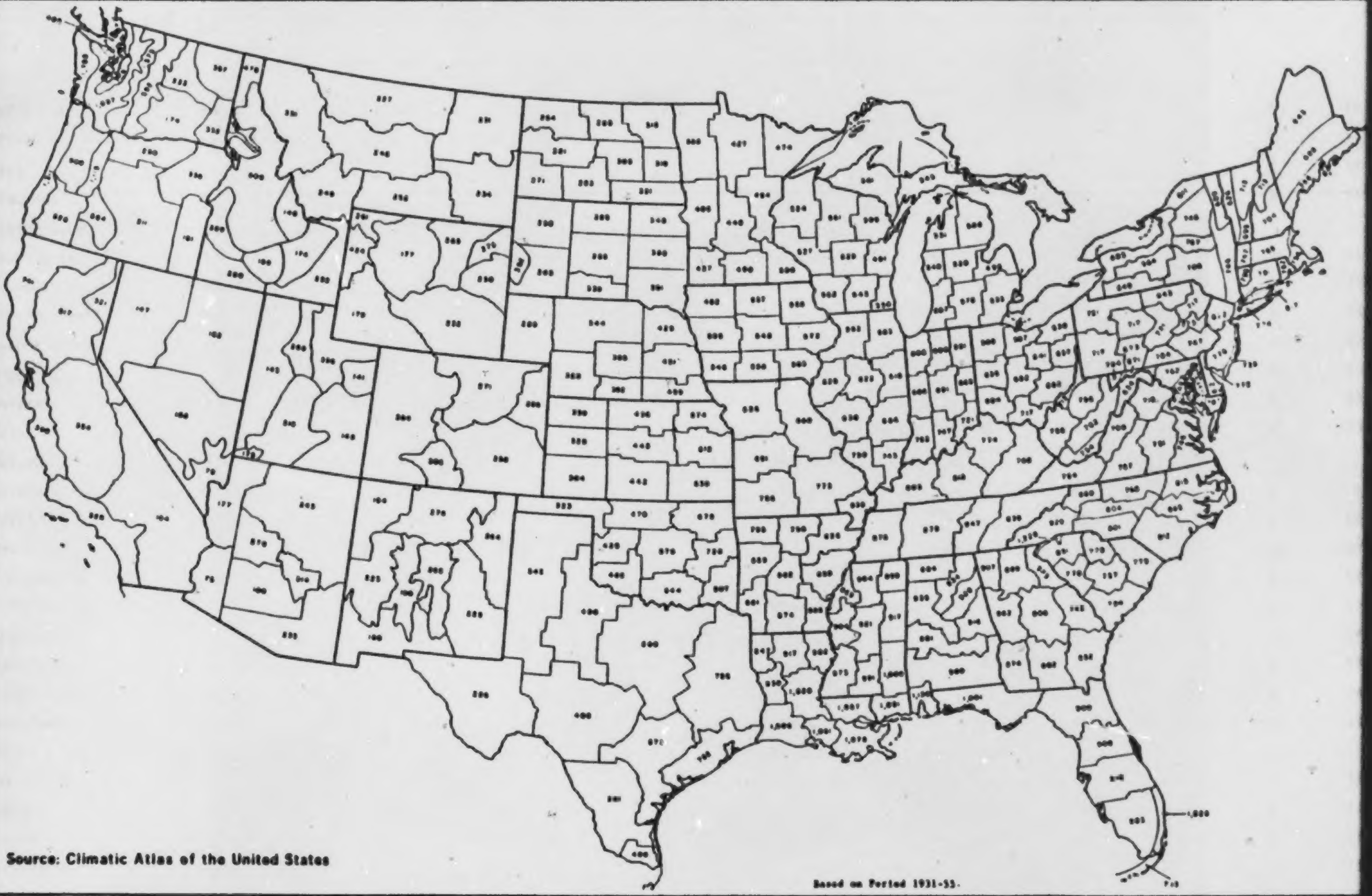
Source:
Selected Climatic Maps of the United States

CAUTION SHOULD BE USED IN INTERPOLATING ON THESE GENERALIZED MAPS, PARTICULARLY IN MOUNTAINOUS AREAS.

Fig. 36 Normal annual total precipitation (inches)

STATION NAME	.01-.19IN	.20-.49IN	.50-.99IN	=>1.00IN	# YEARS
ALABAMA					
ANNISTON	59	25	10	2	18
BIRMINGHAM	74	28	10	3	23
DOTHAN	44	23	10	2	10
GADSDEN	58	28	10	2	16
HUNTSVILLE	74	29	10	3	14
MOBILE	75	27	14	6	14
MONTGOMERY	63	25	9	3	23
MUSCLE SHOALS	60	28	10	2	21
TUSCALOOSA	54	24	10	2	14
ARKANSAS					
EL DORADO	51	23	10	3	23
FAYETTEVILLE	40	27	8	3	4
FORT SMITH	64	20	7	2	24
HARRISON	56	21	7	1	23
HOT SPRINGS	50	24	10	3	17
JONESBORO	48	18	9	3	20
LITTLE ROCK	66	23	10	3	24
TEXARKANA	61	23	10	3	19
FLORIDA					
DAYTONA BEACH	71	25	11	5	25
FT. LAUDERDALE	54	23	13	8	20
FT. MYERS	61	23	14	8	13
GAINESVILLE	53	28	13	5	15
JACKSONVILLE	72	25	12	5	23
MELBOURNE	51	25	11	5	18
MIAMI	75	28	15	6	23
ORLANDO	69	26	13	5	25
PANAMA CITY	44	21	10	5	16
FLORIDA (CONTINUED)					
PENSACOLA	78	25	13	9	5
SARASOTA	45	23	11	5	12
TALLAHASSEE	66	31	16	7	14
TAMPA	62	24	13	5	17
W. PALM BEACH	77	30	15	6	24
GEORGIA					
ALBANY	52	23	8	2	22
ATHENS	72	28	8	2	14
ATLANTA	76	27	9	2	23
AUGUSTA	70	22	8	2	24
COLUMBUS	70	27	10	4	24
MACON	74	24	7	2	24
MOULTRIE	53	24	10	4	23
SAVANNAH	72	25	11	4	24
VALDOSTA	70	24	9	8	2
LOUISIANA					
ALEXANDRIA	47	27	12	4	13
BATON ROUGE	65	25	12	5	25
LAFAYETTE	42	26	12	6	20
LAKE CHARLES	56	24	12	5	23
MONROE	48	22	12	3	17
NEW ORLEANS	66	27	15	6	10
SHREVEPORT	66	21	9	3	17
MISSISSIPPI					
LAUREL-HATTIESBURG	52	27	13	5	22
MERIDIAN	59	28	11	3	24
OXFORD	54	26	9	3	21
TUPELO	48	25	10	2	17

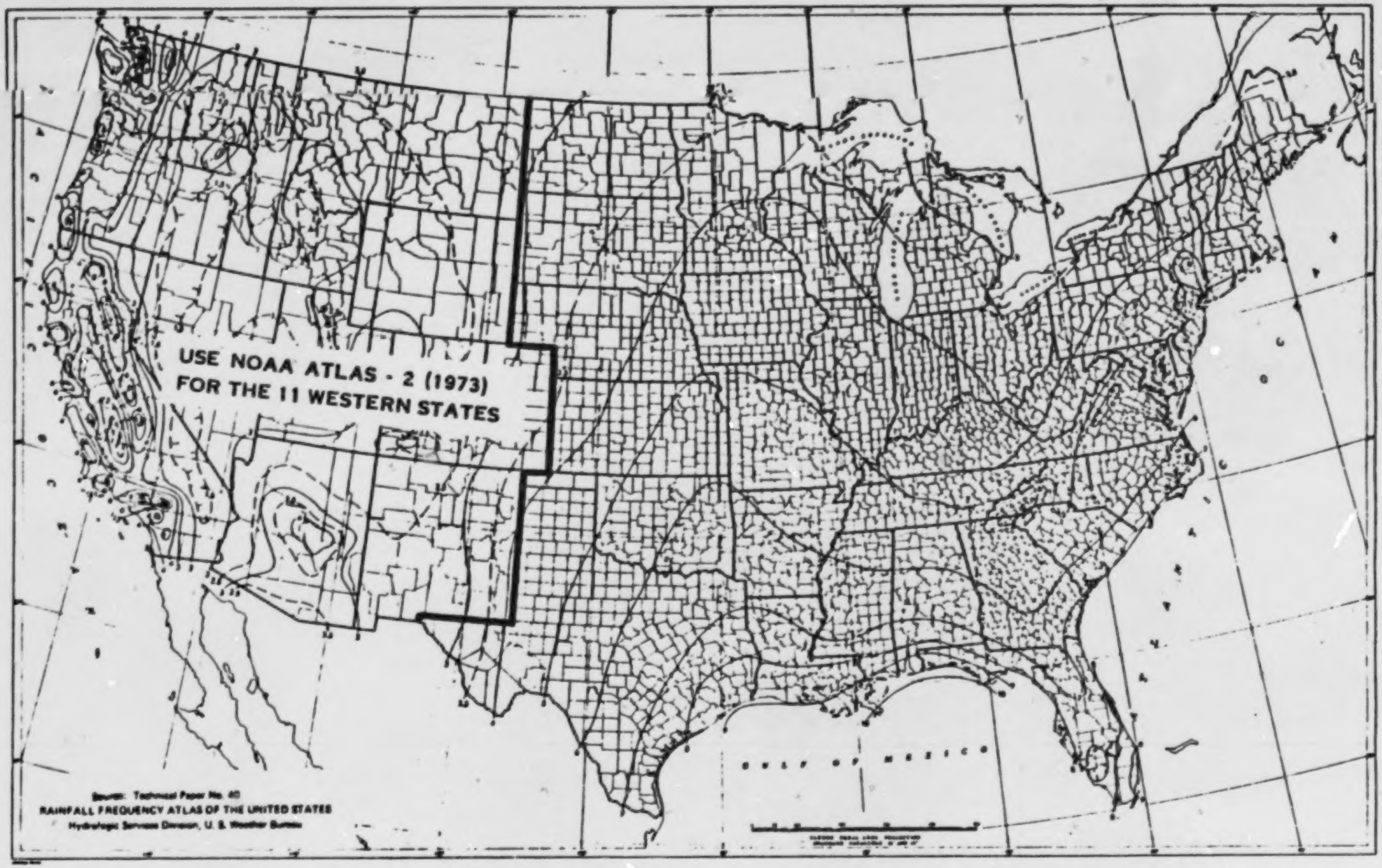
Fig. 37 Probable number of days per year that precipitation rates per hour can be expected



Source: Climatic Atlas of the United States

Based on Period 1931-55.

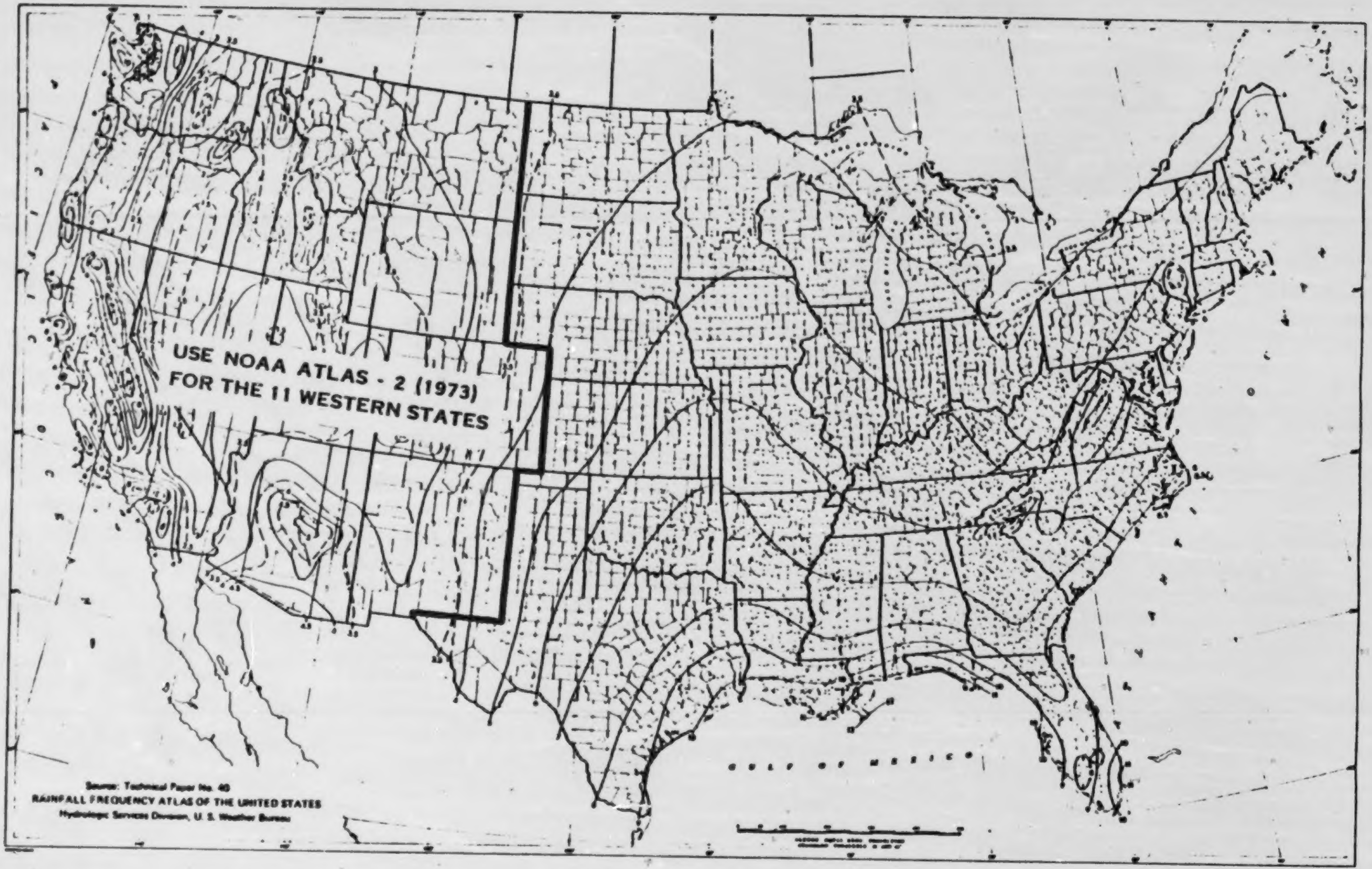
Fig. 38 Mean annual precipitation in millions of gallons of water per square mile, by state climatic divisions


PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO

USE NOAA ATLAS - 2 (1973) FOR THE 11 WESTERN STATES

Source: Technical Paper No. 40
RAINFALL FREQUENCY ATLAS OF THE UNITED STATES
Hydrologic Services Division, U. S. Weather Bureau

Fig. 39 10–year 24–hour rainfall (inches)


USE NOAA ATLAS - 2 (1973)
FOR THE 11 WESTERN STATES
GULF OF MEXICO

Source: Technical Paper No. 40
RAINFALL FREQUENCY ATLAS OF THE UNITED STATES
Hydrologic Services Division, U. S. Weather Bureau

Fig. 40 25—year 24 hour rainfall (inches)

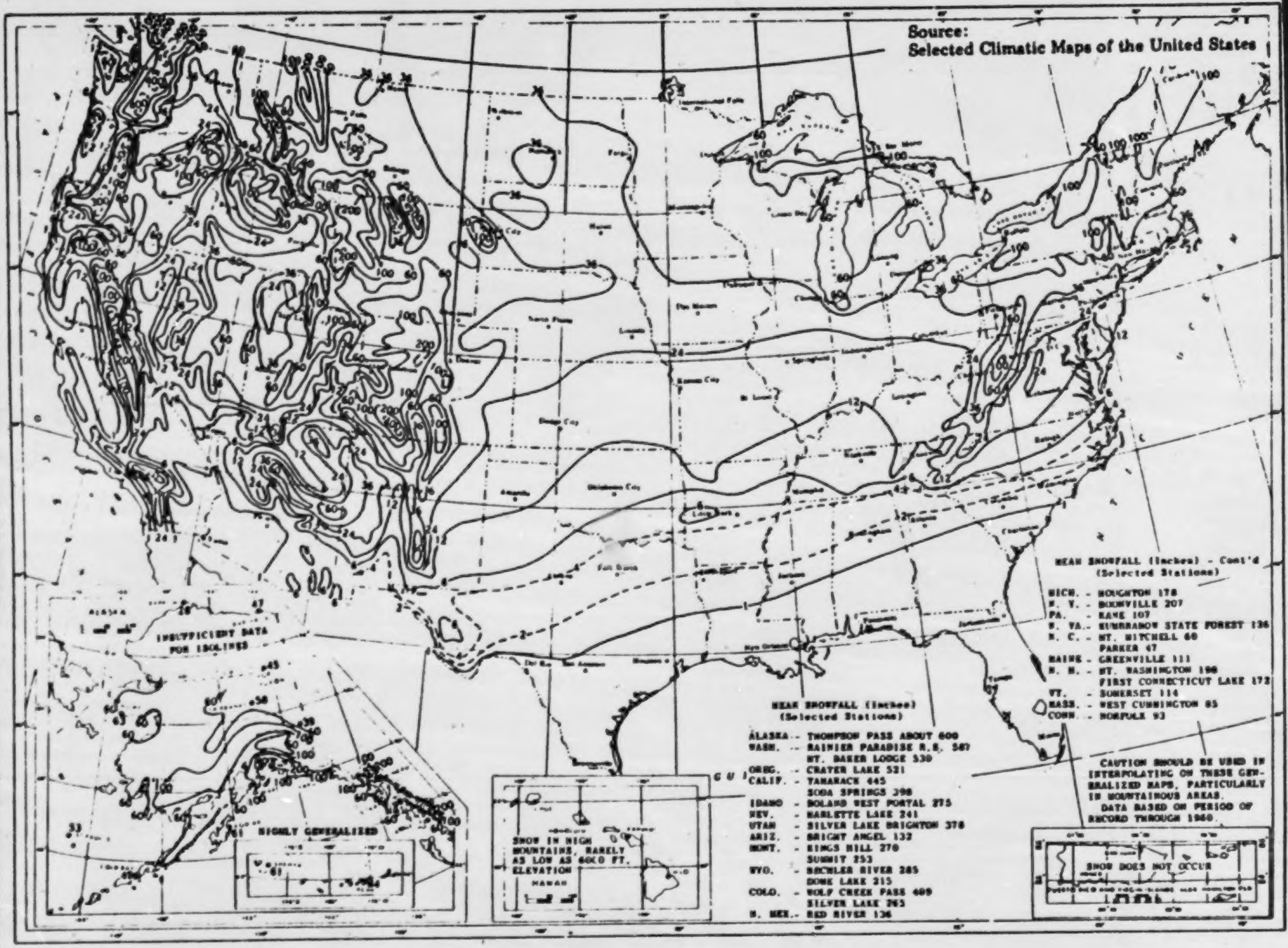
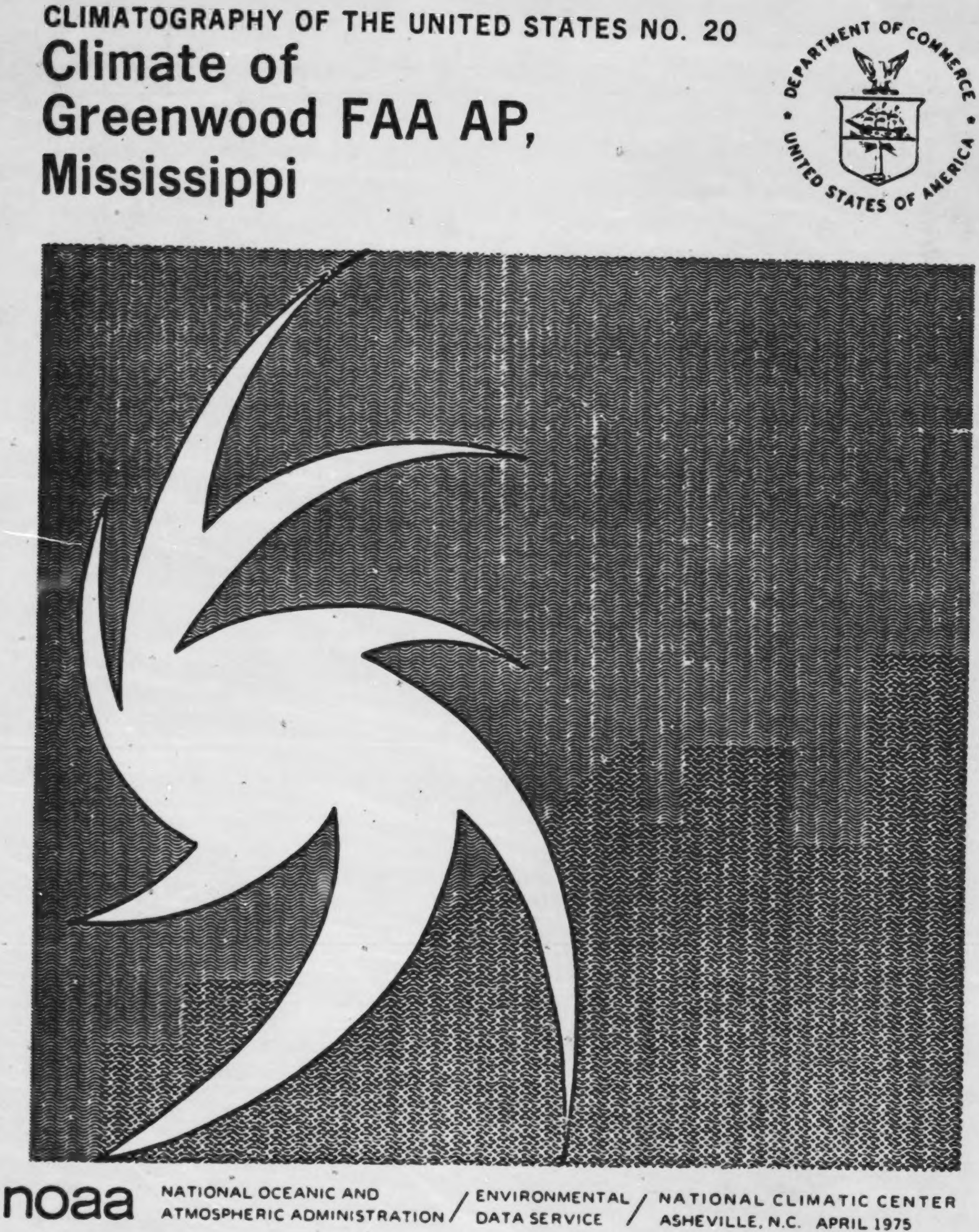

Source:
Selected Climatic Maps of the United States
INSUFFICIENT DATA FOR ISOLINES
HIGHLY GENERALIZED
SNOW IN HIGH MOUNTAINS, RARELY AS LOW AS 6000 FT. ELEVATION
HAWAII
SNOW DOES NOT OCCUR
MEAN SNOWFALL (Inches)
(Selected Stations)
ALASKA -- THOMPSON PASS ABOUT 600
WASH. -- RAINIER PARADISE R.S. 567
MT. BAKER LODGE 530
OREG. -- CRATER LAKE 521
CALIF. - TAMARACK 445
SODA SPRINGS 398
IDAHO - ROLAND WEST PORTAL 275
NEV. - MARLETTE LAKE 241
UTAH - SILVER LAKE BRIGHTON 378
ARIZ. - BRIGHT ANGEL 132
MONT. - KINGS HILL 270
SUMMIT 253
WYO. - BECHLER RIVER 285
DOME LAKE 215
COLO. - WOLF CREEK PASS 409
SILVER LAKE 265
N. MEX.- RED RIVER 136
MEAN SNOWFALL (Inches) - Cont'd
(Selected Stations)
MICH. - HOUGHTON 178
N. Y. - BOONVILLE 207
PA. - KANE 107
W. VA.- KUMBRABOW STATE FOREST 136
N. C. - MT. MITCHELL 60
PARKER 47
MAINE - GREENVILLE 111
N. H. - MT. WASHINGTON 196
FIRST CONNECTICUT LAKE 172
VT. - SOMERSET 114
MASS. - WEST CUMMINGTON 85
CONN. - NORFOLK 93
CAUTION SHOULD BE USED IN INTERPOLATING ON THESE GENERALIZED MAPS, PARTICULARLY IN MOUNTAINOUS AREAS.
DATA BASED ON PERIOD OF RECORD THROUGH 1960.

Fig. 41 Mean annual total snowfall (inches)



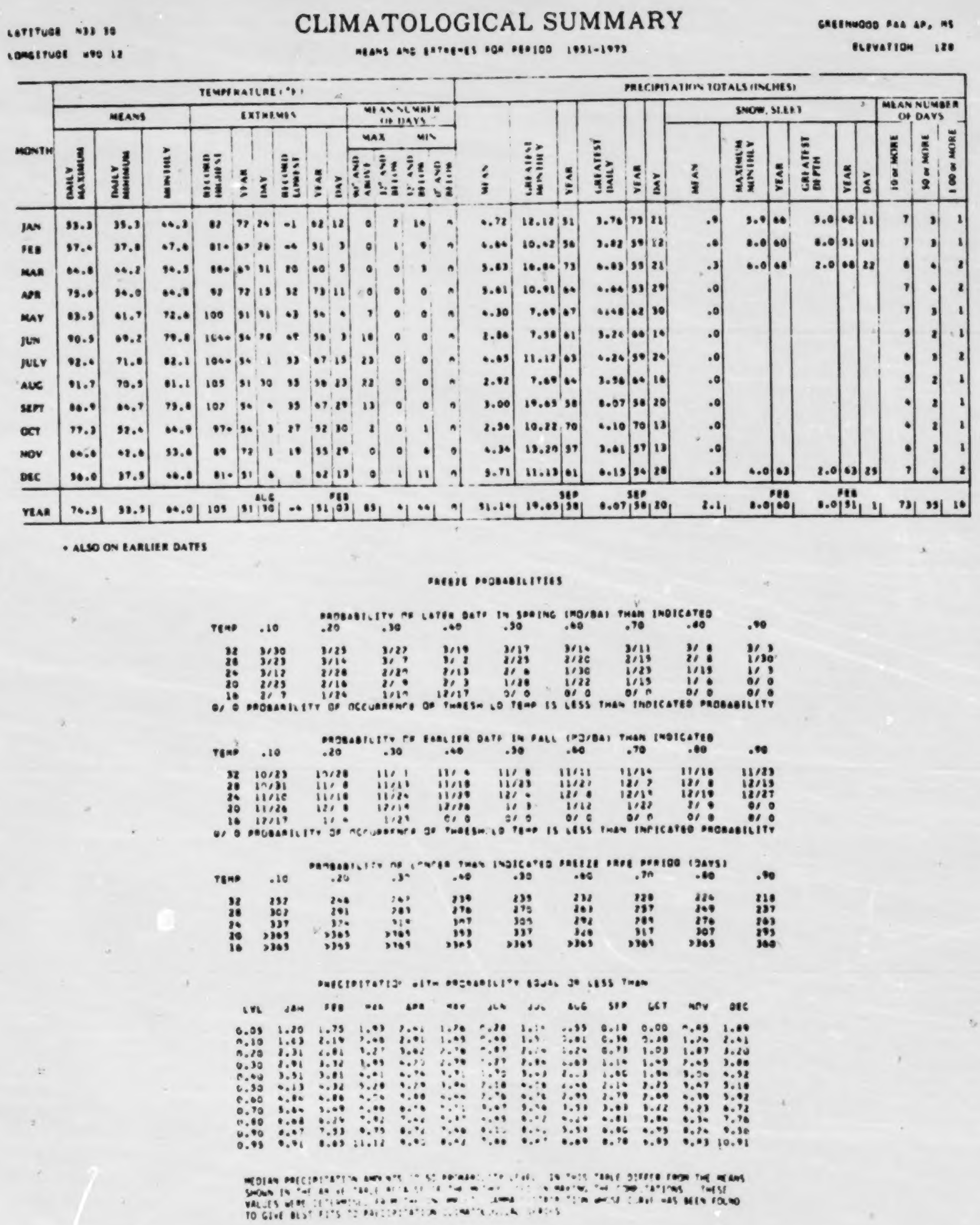
CLIMATOGRAPHY OF THE UNITED STATES NO. 20

Climate of Greenwood FAA AP, Mississippi

DEPARTMENT OF COMMERCE • UNITED STATES OF AMERICA

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / ENVIRONMENTAL DATA SERVICE / NATIONAL CLIMATIC CENTER
ASHEVILLE, N.C. APRIL 1975

Fig. 42 Climatological summary for Greenwood, MS, from the series, "Climatography of the U. S. No. 20"



LATITUDE N33 30
LONGITUDE W90 12

CLIMATOLOGICAL SUMMARY

MEANS AND EXTREMES FOR PERIOD 1951-1973

GREENWOOD FAA AP, MS
ELEVATION 128

MONTH	TEMPERATURE (°F) MEANS: DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	EXTREMES: RECORD HIGHEST	YEAR	DAY	RECORD LOWEST	YEAR	DAY	MEAN NUMBER OF DAYS MAX: 90° AND ABOVE	32° AND BELOW	MIN: 32° AND BELOW	0° AND BELOW	PRECIPITATION TOTALS (INCHES): MEAN	GREATEST MONTHLY	YEAR	GREATEST DAILY	YEAR	DAY	SNOW, SLEET: MEAN	MAXIMUM MONTHLY	YEAR	GREATEST DEPTH	YEAR	DAY	MEAN NUMBER OF DAYS: .10 or MORE	.50 or MORE	1.00 or MORE
JAN	53.3	35.3	44.3	82	72	24	-1	62	12	0	2	14	0	4.72	12.12	51	3.76	73	21	.9	5.9	66	5.0	62	11	7	3	1
FEB	57.4	37.8	47.6	81*	67	26	-4	51	3	0	1	9	0	4.64	10.42	56	3.82	59	12	.6	8.0	60	8.0	51	01	7	3	1
MAR	64.8	44.2	54.5	88*	67	31	20	60	5	0	0	3	0	5.83	16.84	73	6.83	55	21	.3	6.0	68	2.0	68	22	8	4	2
APR	75.0	54.0	64.5	92	72	15	32	73	11	0	0	0	0	5.01	10.91	64	4.64	53	29	.0						7	4	2
MAY	83.3	61.7	72.5	100	51	31	43	54	4	7	0	0	0	4.30	7.69	67	4.48	62	30	.0						7	3	1
JUN	90.5	69.2	79.8	104*	54	28	49	58	3	18	0	0	0	2.86	7.58	61	3.24	66	14	.0						5	2	1
JULY	92.4	71.8	82.1	104*	54	1	53	67	15	23	0	0	0	4.05	11.12	63	4.24	59	24	.0						6	3	2
AUG	91.7	70.5	81.1	105	51	30	55	58	23	22	0	0	0	2.92	7.69	64	3.56	64	16	.0						5	2	1
SEPT	86.9	64.7	75.8	107	54	4	35	67	29	13	0	0	0	3.00	19.65	58	8.07	58	20	.0						4	2	1
OCT	77.3	52.4	64.9	97*	54	3	27	52	30	2	0	1	0	2.56	10.22	70	4.10	70	13	.0						4	2	1
NOV	64.6	42.6	53.6	89	72	1	19	55	29	0	0	6	0	4.34	13.29	57	3.61	57	13	.0						6	3	1
DEC	56.0	37.5	46.8	81*	51	6	8	62	13	0	1	11	0	5.71	11.13	61	4.15	54	28	.3	4.0	63	2.0	63	25	7	4	2
YEAR	74.3	53.9	64.0	105	AUG 51	30	-4	FEB 51	03	85	4	44	0	51.14	19.65	SEP 58	8.07	SEP 58	20	2.1	8.0	FEB 60	8.0	FEB 51	1	73	35	16

* ALSO ON EARLIER DATES

FREEZE PROBABILITIES

PROBABILITY OF LATER DATE IN SPRING (MO/DA) THAN INDICATED

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	3/30	3/25	3/22	3/19	3/17	3/14	3/11	3/ 8	3/ 3
28	3/23	3/14	3/ 7	3/ 2	2/25	2/20	2/15	2/ 8	1/30
24	3/12	2/28	2/20	2/13	2/ 6	1/30	1/23	1/15	1/ 3
20	2/25	2/16	2/ 9	2/ 3	1/28	1/22	1/15	1/ 6	0/ 0
16	2/ 7	1/24	1/19	12/17	0/ 0	0/ 0	0/ 0	0/ 0	0/ 0

0/ 0 PROBABILITY OF OCCURRENCE OF THRESHOLD TEMP IS LESS THAN INDICATED PROBABILITY

PROBABILITY OF EARLIER DATE IN FALL (MO/DA) THAN INDICATED

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	10/23	10/28	11/ 1	11/ 4	11/ 8	11/11	11/14	11/18	11/23
28	10/31	11/ 8	11/13	11/18	11/23	11/27	12/ 2	12/ 8	12/15
24	11/10	11/18	11/24	11/29	12/ 4	12/ 8	12/13	12/19	12/27
20	11/26	12/ 8	12/14	12/28	1/ 3	1/12	1/22	2/ 9	0/ 0
16	12/17	1/ 4	1/23	0/ 0	0/ 0	0/ 0	0/ 0	0/ 0	0/ 0

0/ 0 PROBABILITY OF OCCURRENCE OF THRESHOLD TEMP IS LESS THAN INDICATED PROBABILITY

PROBABILITY OF LONGER THAN INDICATED FREEZE FREE PERIOD (DAYS)

TEMP	.10	.20	.30	.40	.50	.60	.70	.80	.90
32	257	246	242	239	235	232	228	224	218
28	302	291	283	278	275	263	257	249	237
24	337	324	314	307	305	292	289	276	263
20	>365	>365	>365	353	337	320	317	307	295
16	>365	>365	>365	>365	>365	>365	>365	>365	360

PRECIPITATION WITH PROBABILITY EQUAL OR LESS THAN

LVL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0.05	1.20	1.75	1.93	2.41	1.76	0.28	1.14	0.55	0.18	0.00	0.85	1.80
0.10	1.63	2.19	2.48	2.91	1.45	0.46	[illegible]	0.81	0.30	0.08	1.26	2.41
0.20	2.31	2.81	3.27	3.62	2.18	0.87	[illegible]	1.24	0.73	1.03	1.87	3.20
0.30	2.91	3.32	3.95	4.23	2.70	1.27	2.06	1.63	1.14	1.49	2.45	3.88
0.40	3.51	3.81	4.41	4.74	3.31	1.72	3.03	2.13	1.66	1.94	3.36	4.52
0.50	4.13	4.32	5.28	5.29	3.84	2.18	4.10	2.48	2.14	2.25	3.67	5.18
0.60	4.84	4.88	5.76	5.88	4.44	2.76	4.76	2.95	2.79	2.69	4.30	5.92
0.70	5.64	5.49	6.86	6.56	5.13	3.47	5.56	3.53	3.03	3.42	5.23	6.72
0.80	6.68	6.24	7.82	7.46	6.17	4.45	6.47	4.29	4.81	3.84	6.34	7.78
0.90	8.47	7.53	9.75	8.74	7.40	6.13	8.44	5.54	6.06	4.95	8.24	9.30
0.95	9.91	8.85	11.12	9.82	8.47	7.88	[illegible]	8.60	8.78	6.89	9.83	10.91

MEDIAN PRECIPITATION AMOUNTS (0.50 PROBABILITY LEVEL) IN THIS TABLE DIFFER FROM THE MEANS SHOWN IN THE ABOVE TABLE BECAUSE OF THE METHOD USED IN MAKING THE COMPUTATIONS. THESE VALUES WERE DETERMINED FROM THE GAMMA DISTRIBUTION WHOSE CURVE HAS BEEN FOUND TO GIVE BEST FITS TO PRECIPITATION CLIMATOLOGICAL SERIES.

Fig 42a Climatological summary for Greenwood, MS, from the series, "Climatography of the U.S. No. 20"

STATION: 22 3627 MAX TEMP

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	56.0	59.1	66.1	72.6	85.4	90.1	93.3	96.7	88.3	75.9	59.3	59.8	75.3
52	61.0	61.7	63.8	72.2	83.9	97.3	97.3	94.3	87.5	72.6	62.8	55.0	75.9
53	59.6	59.1	70.2	73.1	85.1	97.3	92.4	92.7	90.1	80.7	65.3	53.0	76.6
54	57.3	64.8	65.6	80.1	77.0	93.9	97.5	98.6	93.0	78.7	64.3	58.4	77.3
55	53.6	57.9	69.0	78.0	86.3	87.5	92.3	91.6	91.3	77.6	63.3	55.7	75.4
56	51.3	61.7	65.7	74.0	88.4	88.6	94.5	95.6	88.8	79.4	63.8	62.8	76.0
57	53.0	62.6	62.9	77.3	83.8	88.6	91.5	90.3	80.9	69.9	61.9	59.3M	73.6M
58	49.6	48.1	57.3	76.0	83.1	88.8	91.4	90.6	83.3	76.9	66.3	50.0	71.6
59	52.7	58.3	65.9	76.5	85.8	87.5	91.0	91.6	86.4	76.3	61.3	56.0	74.0
60	50.8	50.2	53.4	78.2	81.8	90.3	94.6	90.9	88.1	77.0	65.3	50.6	72.3
61	48.9	61.5	69.0	72.3	81.1	85.7	88.9	89.3	85.7	77.0	61.8	54.0	72.9
62	49.1	65.6	59.4	73.2	88.6	88.5	94.6	93.7	86.4	78.3	61.7	52.3	74.3
63	47.7	53.0	72.6	77.7	84.9	91.1	90.0	91.4	85.1	84.8	66.0	46.0	74.0
64	53.7	53.0	66.6	77.0	84.3	91.9	92.0	90.1	86.8	73.3	67.3	57.4	74.3
65	55.7	56.3	56.2	79.4	88.8	90.0	93.6	91.6	89.7	75.3	69.3	59.3	75.0
66	48.2	56.2	67.4	75.2	82.1	89.1	95.5	89.7	83.3	73.8	67.3	53.7	73.1
67	54.4	52.9	71.6	73.0	78.4	88.6	86.9	86.5	80.1	76.5	64.4	58.0	72.8
68	50.1M	49.9	63.4	73.6	79.3	89.7	88.3	88.7	82.7	76.4	62.8	54.3	71.6M
69	54.0	55.4	57.9	75.0	84.0	90.9	95.7	90.9	86.1	76.9	64.9	56.9	74.0
70	49.3	55.9	62.7	77.3	86.3	90.8	91.3	92.1	91.7	76.9	65.0	61.9	75.1
71	56.7	60.0	63.3	76.3	81.5	92.6	91.4	91.3	88.7	83.8	68.7	65.1	76.6
72	60.0	61.6	69.3	78.1	83.6	90.9	90.9	93.5	91.2	78.0	61.2	58.3	76.4
73	53.3	56.9	71.8	70.3M	79.2	91.0	90.8	88.9	87.2	80.9	70.1	55.2	74.7M
SUM	1226.2	1319.1	1491.3	1736.0	1919.9	2080.9	2129.9	2108.4	1998.6	1770.3	1485.1	1287.6	1713.6

STATION: 22 3627 MIN TEMP

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	37.0	38.6	47.4	51.1	59.2	70.2	73.2	71.8	64.8	52.9	38.1	41.1	53.9
52	44.4	43.8	43.5	49.6	60.3	72.1	71.9	71.6	60.4	39.6	40.7	36.3	52.9
53	39.9	39.3	49.9	49.1	64.3	73.8	72.7	69.2	60.4	50.5	37.9	33.9	52.6
54	38.4	41.3	43.6	57.4	57.6	69.6	73.4	73.1	64.4	54.1	39.9	33.2	54.0
55	36.9	38.4	46.4	57.2	64.0	64.4	72.7	70.5	65.6	48.8	40.0	37.1	53.3
56	32.2	42.9	43.0	52.0	65.0	68.1	71.5	69.9	59.8	54.4	40.4	44.1	53.6
57	37.3	46.6	43.2	55.0	63.0	70.9	71.6	69.3	65.2	51.2	45.9	40.2M	55.0M
58	31.6	30.3	41.8	53.2	63.2	67.9	72.7	70.3	67.6	53.3	44.3	32.8	52.3
59	32.5	39.6	42.0	52.1	65.3	68.9	71.3	72.3	66.2	57.2	38.1	38.6	53.7
60	38.1	33.9	36.8	54.8	58.9	69.0	72.1	72.2	66.3	55.0	41.3	33.2	52.6
61	29.6	41.1	49.9	49.6	58.9	66.3	70.2	69.1	64.7	50.0	44.9	37.9	52.7
62	30.8	44.3	41.5	51.4	64.9	69.5	73.2	71.9	65.9	57.2	43.2	34.0	54.0
63	28.2	30.5	47.8	57.3	62.7	70.2	71.2	71.8	63.7	56.3	44.3	27.6	52.8
64	33.7	33.6	43.2	57.4	63.6	70.3	71.5	71.2	64.9	48.9	46.3	39.4	53.7
65	36.8	36.6	39.8	57.3	65.1	69.1	72.4	71.3	67.0	51.1	49.8	38.4	54.8
66	31.9	38.6	44.3	54.3	60.8	67.1	73.7	69.1	63.7	48.4	46.1	37.7	53.0
67	37.1	34.0	47.6	58.1	59.6	68.9	69.1	67.2	59.7	48.1	39.2	40.4	52.4
68	35.5M	31.6	43.6	55.7	61.7	68.9	69.7	70.3	61.4	53.3	44.1	36.0	52.7M
69	38.0	38.6	39.6	56.3	62.1	69.8	73.2	68.6	63.1	54.0	40.0	35.7	53.2
70	32.8	36.9	43.0	58.0	61.3	68.8	70.3	71.5	67.8	51.8	41.2	40.0	53.4
71	37.2	37.2	41.0	51.2	58.1	70.4	71.7	71.1	68.9	58.2	42.6	48.1	54.7
72	40.4	39.4	45.7	54.3	60.9	67.4	70.0	69.9	69.3	53.8	42.4	38.8	54.5
73	35.1	34.1	50.0	49.3M	57.3	67.8	71.6	66.7	60.8	56.3	48.9	33.3	53.3M
SUM	812.5	869.4	1016.6	1242.1	1418.4	1590.6	1650.9	1621.0	1487.6	1204.5	980.0	862.2	1229.6

STATION: 22 3627 AVERAGE TEMPERATURE

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	46.8	48.6	56.8	62.0	72.3	80.2	83.3	84.8	76.6	63.9	48.8	50.3	64.7
52	53.0	52.8	53.7	60.8	72.1	84.7	84.7	83.2	74.0	56.1	51.8	45.8	64.6
53	49.8	49.2	60.1	61.1	74.8	85.7	82.6	81.0	75.3	65.6	51.6	43.3	65.0
54	47.9	53.1	54.7	68.8	67.3	81.8	85.5	85.9	78.7	66.4	52.2	45.8	65.7
55	44.3	48.2	57.7	67.6	75.2	76.0	82.5	81.1	78.5	63.2	51.6	46.4	64.4
56	41.8	52.3	54.4	63.0	75.7	78.4	83.0	82.7	74.3	66.9	52.1	53.5	64.8
57	45.2	54.6	53.1	66.3	73.4	79.8	81.6	80.0	73.1	60.6	53.9	49.9M	64.3M
58	40.6	39.3	49.7	63.6	73.2	79.4	82.1	80.4	76.5	63.6	55.5	41.4	62.1
59	42.6	49.1	54.0	63.3	75.7	78.2	81.2	82.0	76.3	66.8	49.7	47.3	63.9
60	44.5	42.1	45.1	66.5	70.4	79.7	83.4	81.6	76.2	66.0	53.4	41.9	62.6
61	39.3	51.3	59.5	61.0	70.0	76.1	79.6	79.2	75.2	63.5	53.4	46.0	62.8
62	40.0	55.0	50.5	62.3	76.8	79.0	83.9	82.8	76.2	67.8	52.5	43.3	64.2
63	38.0	41.8	60.2	67.5	73.8	80.7	80.6	81.5	74.4	69.7	55.3	35.8	63.3
64	43.7	43.3	54.9	67.2	74.0	81.2	81.8	80.7	75.9	61.2	56.8	48.4	64.1
65	46.3	46.6	48.0	68.3	76.8	79.6	83.0	81.4	78.4	63.3	59.0	48.9	64.8
66	39.0	46.4	55.9	64.8	71.5	78.1	84.6	79.4	73.5	61.1	56.7	45.7	63.1
67	45.8	43.5	59.3	68.1	69.0	78.8	78.0	75.9	69.9	62.3	51.8	49.2	62.7
68	42.8M	40.8	53.5	64.7	70.6	79.3	79.0	79.6	72.1	65.0	53.5	45.2	62.2M
69	46.3	47.0	48.8	65.8	73.4	79.9	84.5	79.7	74.8	65.8	52.5	46.3	63.6
70	40.8	45.4	53.2	67.7	74.0	79.7	80.8	81.8	79.8	64.3	53.1	51.0	64.3
71	47.0	48.6	52.6	63.9	69.8	81.5	81.6	81.2	78.8	71.1	55.7	56.6	65.7
72	50.2	50.5	57.5	66.2	72.3	79.2	80.5	81.7	80.3	66.9	51.8	48.7	65.5
73	44.3	45.5	60.9	59.9M	68.4	79.6	81.2	77.8	77.0	68.7	59.5	45.4	64.0M
SUM	1020.0	1094.8	1234.5	1490.6	1669.7	1838.4	1889.0	1865.4	1743.6	1491.8	1233.0	1073.3	1472.2

Fig. 42b Climatological summary for Greenwood, MS, from the series, "Climatography of the U.S. No. 20"

STATION: 22 3627 TOTAL PRECIPITATION

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
51	12.12	3.66	8.28	6.27	.82	6.08	6.71	1.39	3.96	2.91	2.61	10.24	61.03
52	3.80	3.00	5.12	3.61	4.93	.34	1.34	6.18	1.06	T	3.80	4.51	35.39
53	4.01	7.70	6.16	9.33	5.95	.22	3.75	.73	1.10	.63	1.03	5.80	46.49
54	6.14	2.98	2.06	5.68	7.31	.56	2.09	1.19	.82	2.39	3.70	7.66	42.36
55	4.18	4.95	8.37	7.09	3.46	2.83	4.28	.89	.34	1.28	1.76	3.12	42.70
56	2.55	10.42	4.60	6.39	2.66	1.34	3.67	.70	.16	3.90	4.43	6.72	47.72
57	8.43	3.75	5.85	3.69	3.67	4.96	2.93	2.76	3.48	5.07	13.20	2.48	62.06
58	2.84	3.16	4.85	8.90	7.12	4.13	9.31	2.55	19.63	.91	1.76	.97	66.13
59	1.71	6.47	3.41	5.51	6.08	2.73	8.16	4.53	1.23	2.49	2.91	5.30	50.33
60	6.60	3.32	3.61	2.48	3.06	1.08	1.74	7.60	3.11	1.30	4.27	5.38	46.33
61	1.28	8.56	10.10	3.49	1.13	7.38	7.34	2.25	1.20	1.10	11.09	11.13	66.91
62	5.88	4.85	3.32	4.86	5.45	4.69	1.22	1.34	4.91	4.82	4.77	2.67	48.78
63	2.26	2.66	4.99	2.55	1.45	2.28	11.12	1.43	.46	.00	3.12	5.50	37.78
64	3.49	3.33	6.71	10.91	3.35	1.16	3.02	7.09	3.39	2.02	4.73	3.91	53.73
65	1.78	6.90	6.95	3.13	1.76	.88	2.02	2.78	2.92	1.04	1.04	1.91	32.31
66	5.17	7.95	1.08	4.33	2.85	4.64	1.08	1.17	4.77	1.85	1.30	5.24	42.19
67	1.32	4.98	2.36	4.00	7.69	2.89	2.30	3.38	.80	2.00	2.78	10.73	45.53
68	8.06	2.30	4.69	8.29	6.56	2.12	4.11	4.06	5.76	2.66	7.92	5.40	62.07
69	4.23	3.13	4.68	5.48	2.73	1.38	4.00	4.32	3.38	2.46	2.63	9.77	48.31
70	1.67	5.34	6.74	8.28	2.24	3.18	4.39	3.42	1.35	10.22	5.59	4.71	53.29
71	3.25	4.66	5.29	6.37	5.26	5.38	7.68	4.31	1.20	1.46	1.30	5.96	52.08
72	8.25	1.21	6.00	4.98	4.62	3.35	4.80	5.66	3.22	3.38	8.40	5.63	57.70
73	9.23	3.80	10.86	6.40	7.03	.83	10.93	.50	.44	4.13	6.99	6.85	74.07
SUM	108.47	106.81	134.06	129.04	98.98	65.71	106.93	67.19	69.09	58.81	99.77	131.43	1176.29

STATION: 22 3627 TOTAL SNOWFALL

SEASON	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	SEASON
50-51							2.7	5.0	T	.0	.0	.0	
51-52	.0	.0	.0	.0	T	T	.0	.3	T	.0	.0	.0	.3
52-53	.0	.0	.0	.0	.0	.0	T	.0	T	.0	T	.0	.0
53-54	.0	.0	.0	.0	.0	T	T	.0	.0	.0	.0	.0	.0
54-55	.0	.0	.0	.0	.0	.0	T	.0	.0	.0	.0	.0	.0
55-56	.0	.0	.0	.0	.0	.0	T	.0	.0	.0	.0	.0	.0
56-57	.0	.0	.0	.0	.0	.0	.0	.0	T	.0	.0	.0	.0
57-58	.0	.0	.0	.0	.0	.0	1.0	T	.0	.0	.0	.0	1.0
58-59	.0	.0	.0	.0	.0	2.0	T	.0	.0	.0	.0	.0	2.0
59-60	.0	.0	.0	.0	.0	T	.0	8.0	T	.0	.0	.0	8.0
60-61	.0	.0	.0	.0	.0	T	T	T	.0	.0	.0	.0	.0
61-62	.0	.0	.0	.0	.0	.0	5.0	.0	.0	.0	.0	.0	5.0
62-63	.0	.0	.0	.0	.0	T	T	T	.0	.0	.0	.0	.0
63-64	.0	.0	.0	.0	.0	4.0	.3	.0	.0	.0	.0	.0	4.3
64-65	.0	.0	.0	.0	.0	T	T	.8	T	.0	.0	.0	.8
65-66	.0	.0	.0	.0	.0	.0	5.9	T	.0	.0	.0	.0	5.9
66-67	.0	.0	.0	.0	T	T	.4	T	T	.0	.0	.0	.4
67-68	.0	.0	.0	.0	T	1.0	1.0	.3	6.0	.0	.0	.0	8.3
68-69	.0	.0	.0	.0	.0	T	.0	.1	T	.0	.0	.0	.1
69-70	.0	.0	.0	.0	.0	.0	T	T	.0	.0	.0	.0	.0
70-71	.0	.0	.0	.0	.0	.0	4.0	T	T	T	.0	.0	4.0
71-72	.0	.0	.0	.0	T	.0	.0	T	.0	.0	.0	.0	.0
72-73	.0	.0	.0	.0	.0	.0	T	.0	.0	.0	.0	.0	.0
73-74	.0	.0	.0	.0	.0	T							
SUM	.0	.0	.0	.0	.0	7.0	20.5	14.7	6.0	.0	.0	.0	40.3

E AMOUNT IS WHOLLY OR PARTLY ESTIMATED.

T TRACE, AN AMOUNT TOO SMALL TO MEASURE.

M ONE OR MORE DAYS OF RECORD MISSING; IF AVERAGE VALUE IS ENTERED, LESS THAN 10 DAYS RECORD IS MISSING.

B WATER EQUIVALENT OF SNOWFALL WHOLLY OR PARTLY ESTIMATED.

MONTHLY NORMALS OF TEMPERATURE, PRECIPITATION AND HEATING AND COOLING DEGREE DAYS (1941-70)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
TEMPERATURE	44.6	47.8	54.5	65.1	72.8	79.9	82.0	81.2	75.1	64.8	53.5	46.3	64.0
PRECIPITATION	4.87	5.06	5.83	5.15	4.31	3.31	4.14	2.99	3.24	2.56	4.30	5.28	51.32
HEATING DEGREE DAY	632	489	353	77	9	0	0	0	0	108	349	580	2598
COOLING DEGREE DAY	0	8	28	80	231	447	527	502	306	103	0	0	2232

Fig. 42c Climatological summary for Greenwood, MS, from the series, "Climatography of the U.S. No. 20

EVAPORATION MAPS FOR THE UNITED STATES

Hydrologic Investigations Section, Hydrologic Services Division,
U. S. Weather Bureau, Washington, D. C.

Since evaporation inevitably extracts a portion of the gross water supply to a reservoir, the estimation of this loss is an important factor in reservoir design. In arid regions, the evaporation loss actually imposes a ceiling on the water supply obtainable through regulation. Speaking of storage on the main stem of the Colorado River, Langbein [30] states that "The gain in regulation to be achieved by increasing the present 29 million acre-feet to nearly 50 million acre-feet of capacity appears to be largely offset by a corresponding increase in evaporation."

In the final stages, the design of major storage projects requires detailed study of all data available, including observations made at the proposed reservoir sites. However, generalized estimates of free-water evaporation are invaluable in preliminary design studies of major projects, and are often fully adequate for the design of lesser projects. The maps presented herein have been prepared to serve these purposes, primarily, but they should be of value in other studies. For example, free-water evaporation [Figure 44] is a good index to potential evapotranspiration, or consumptive use, and the pan coefficient [Figure 45] is indicative of an aspect of climate. If solar radiation, wind, dew point, and air temperature are such that water in an exposed Class A pan is warmer than the air, the coefficient is greater than 0.7, and vice versa.

In 1942, A. F. Meyer [31] published a map comparable to that in Figure 44, and in the following year R. E. Horton [32] published a map of Class A pan evaporation similar to Figure 43. Subsequent to 1942, there has been a substantial increase in the Class A pan station network and significant progress in the development of techniques for estimating lake evaporation. However, the maps prepared by Horton and Meyer were carefully studied in the preparation of the new series -- any pronounced differences are considered to be reasonably substantiated by data now available.

Figure 45 shows the ratio of annual lake evaporation to that from the Class A pan. It can be used to estimate free-water evaporation for any site for which representative pan data are available. Figure 46 has been included to assist in the extrapolation of seasonal pan evaporation data to annual values, as well as to provide an indication of the seasonal distribution of evaporation from a shallow free-water body. Figure 47 shows the variability of pan evaporation, year-to-year, and can be used to estimate the frequency distribution of annual lake evaporation. The correct interpretation and use of these plates are discussed later.

METHODS FOR COMPUTING EVAPORATION - - The various methods for computing pan and lake evaporation are described in the Lake Hefner [33] and Lake Mead [34] Water-Loss Investigations Reports, and in Weather Bureau Research Paper No. 38 [35]. There are four generally accepted methods of computing lake evaporation: (a) water budget, (b) energy budget, (c) mass transfer, and (d) lake-to-pan relations. Very few reliable water-budget estimates are available because small errors in volume of inflow and outflow usually result in large errors in the residual evaporation value. The energy-budget approach requires such elaborate instrumentation that it is only feasible for special investigations. The mass-transfer method requires observations of lake surface-water temperature, dew point, and wind movement which are available for only a very few reservoirs. Methods (a), (b), and (c) are only applicable for existing lakes and reservoirs, and cannot be used in the design phase.

The few lake-evaporation determinations that have been made using water-budget, energy-budget, and mass-transfer methods were used in preparing Figs. 44-45. However, from a practical point of view, the lake-evaporation map is based essentially on pan evaporation and related meteorological data collected at Class A evaporation and first-order synoptic stations.

DEVELOPMENT OF MAPS - - The description of the development of the maps is given in Weather Bureau Technical Paper No. 37 "Evaporation Maps for the United States."

INTERPRETATION, USE, AND LIMITATIONS OF MAPS - - Although the utility of the derived maps hinges largely on their reliability, it is virtually impossible to make any meaningful generalizations in this respect. In deriving Figures 43-45, all available pertinent data were utilized to the greatest extent feasible with present-day knowledge of the relationships involved. It can be reasonably assumed, therefore, that the maps provide the most accurate generalized estimates yet available. The reliability of the maps is obviously poorer in the areas of high relief than in the plains region, and the density of the observation network is an important factor throughout.

It is known that some of the data collected over the years are from sheltered sites which are not representative. Through subjective evaluation of the station descriptions and wind data, an attempt was made to derive pan evaporation and coefficient maps indicative of a representative exposure, reasonably free of obstructions to wind and sunshine. Variations in the data were smoothed to a considerable extent, and it is entirely possible that the true areal variation in evaporation exceeds that shown on the maps. For example, a pan or small reservoir located in a canyon of northerly orientation and partially shielded from the sun would experience considerably less evaporation than indicated by the maps.

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The effect of topography has been taken into account only in a general way, except where the data provided definite indications. Thus, it will be noted that the isopleths tend to follow closely the topographic features in some portions of the maps while the resemblance is more casual in other areas. Both Class A pan and lake evaporation were assumed to decrease with elevation however, the decrease assumed for lake evaporation is less. With an increase in elevation, dew point and air temperatures tend to decrease, while wind movement usually increases. Solar radiation, on the other hand, increases upslope during cloudless days and may otherwise increase or decrease depending on the variation of cloudiness with elevation. There are but few reliable observations of the variation of all these factors up mountain slopes, but it is probable that the effect of these changes is less for lake evaporation than for pan evaporation.

There is good reason to expect that Figure 46, showing seasonal distribution of pan evaporation, is more reliable than any other map in the series. Fig. 47, on the other hand, is based on a sparse network, and time trends resulting from changes in site, exposure, etc., may have caused some bias in the derived values of standard deviation. Data which were obviously inconsistent were eliminated from the analysis, but any undetected inconsistencies result in values which tend to be too high. Even so, any bias in the final, smoothed isopleths should be small.

The use of Figs. 43-47 is self-evident in most respects and need not be considered further here. Certain limitations and less obvious features are discussed in the following paragraphs.

Figs. 43, 44 and 45. Unless the user has at hand pan-evaporation data not considered in the development of this series of maps, average annual lake evaporation can be taken directly from Figure 44. The value so determined will also suffice if pan-evaporation data collected at the site substantiate that given by Figure 43. If the pan evaporation at the site exceeds that given by Fig. 43, application of the pan coefficient (Figure 45) will probably provide a better estimate of lake evaporation than that given by Figure 44. If, on the other hand, observed pan evaporation is less than that given by Figure 43, a value of lake evaporation less than given by Figure 44 should be accepted only after it has been determined that the pan site is reasonably free of obstructions to wind and sunshine. This is to say that pan evaporation and the pan coefficient are both dependent upon exposure.

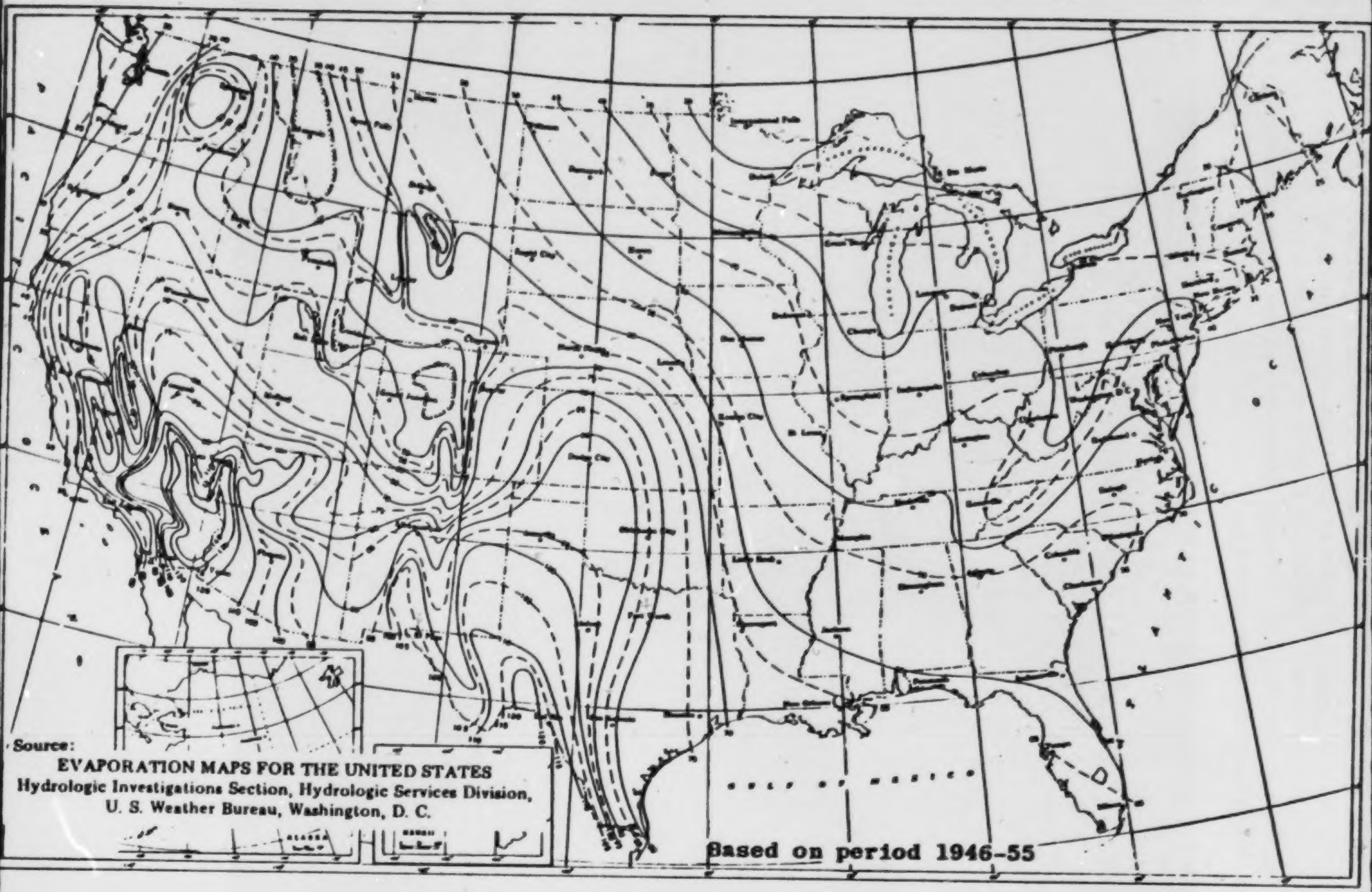
It should be emphasized that values of free-water evaporation given by Fig. 44 (or Figs. 43 and 45) assume that there is no net advection (heat content of inflow less outflow) over a long period of time. The mean annual advection is usually small and can be neglected, but this is not always the case. It was found at Lake Mead, for example, that advection results in a 5-inch increase in mean annual evaporation. If the advection term is appreciable, adjustment should be made as discussed in references [34] and [35].

Figure 46. The Class A pans are not in operation during the winter months over much of the country because of freezing weather. Fig. 46 provides means of estimating average annual evaporation from that observed during the open season, May through October. When used in conjunction with Fig. 43, it also provides a means of estimating average growing-season evaporation (Class A pan) which is so important in some studies.

Although the seasonal ratios of Fig. 46 are based on Class A pan data, it is believed that they are equally applicable to free-water evaporation for shallow lakes. The ratios based on monthly computed lake evaporation for the first-order stations showed no significant deviation from those based on the pan values. It should be emphasized that the seasonal ratios can be applied to annual lake evaporation only in case of shallow lakes where energy storage can be ignored. In deep lakes, the energy storage becomes an important factor in determining seasonal or monthly evaporation. For example, at Lake Mead the maximum lake evaporation occurs in August, but maximum Class A pan evaporation is observed in June; for Lake Ontario, the maximum lake evaporation is in September, and maximum pan evaporation in July. Corrections can be made for changes in energy storage and heat advection into or out of the lake in the manner described in references [34] and [35].

Figure 47. The standard deviation of annual Class A pan evaporation can be obtained for any selected site directly from Fig. 47. If the annual pan coefficient were constant, year-to-year, then the standard deviation of lake evaporation would be the product of that for pan evaporation and the pan coefficient. Because of variation in the annual pan coefficient, the standard deviation computed in this manner may be a few percent too low. Since the values given by Figure 47 are probably biased on the high side (discussed previously), the two possible errors tend to compensate.

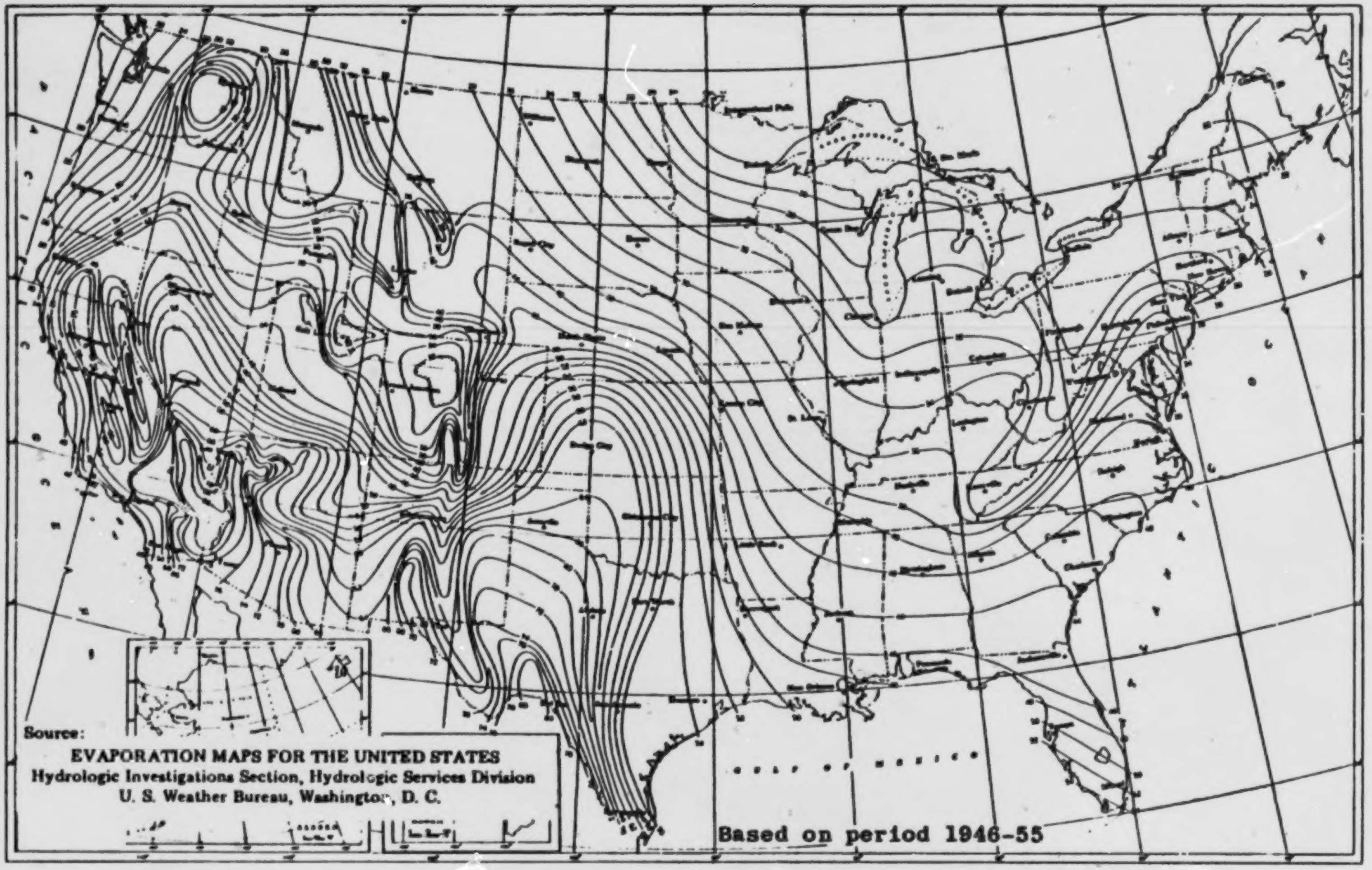
Having obtained the mean and standard deviation, the frequency distribution of annual lake (or pan) evaporation can be derived, assuming the data are normally distributed. If it is further assumed that the annual evaporation totals occurring in successive years are independent, the frequency distribution of n-year evaporation can also be derived.



Source:
EVAPORATION MAPS FOR THE UNITED STATES
Hydrologic Investigations Section, Hydrologic Services Division,
U. S. Weather Bureau, Washington, D. C.

Based on period 1946-55

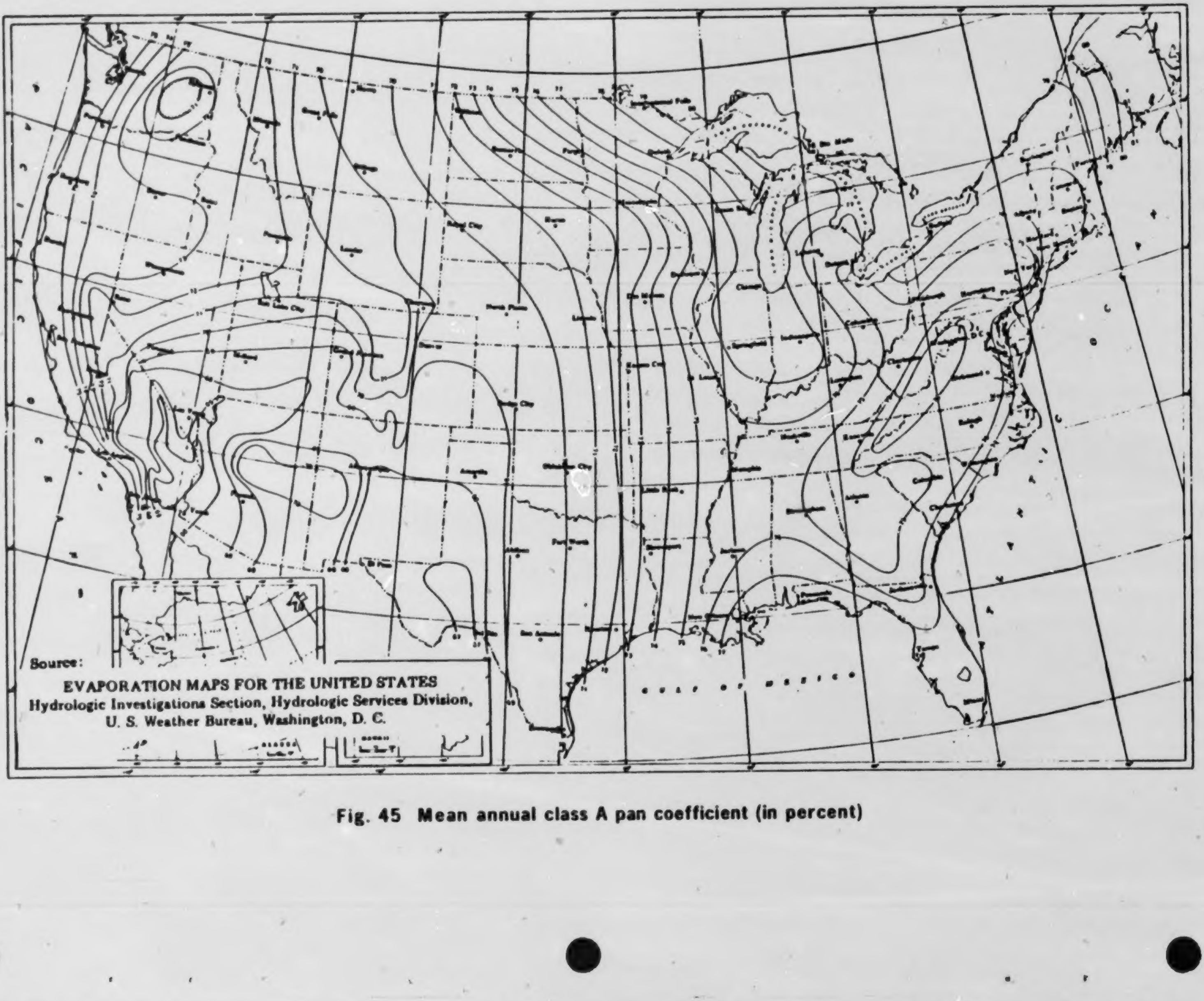
Fig. 43 Mean annual class A pan evaporation (in inches)



Source:
EVAPORATION MAPS FOR THE UNITED STATES
Hydrologic Investigations Section, Hydrologic Services Division
U. S. Weather Bureau, Washington, D. C.

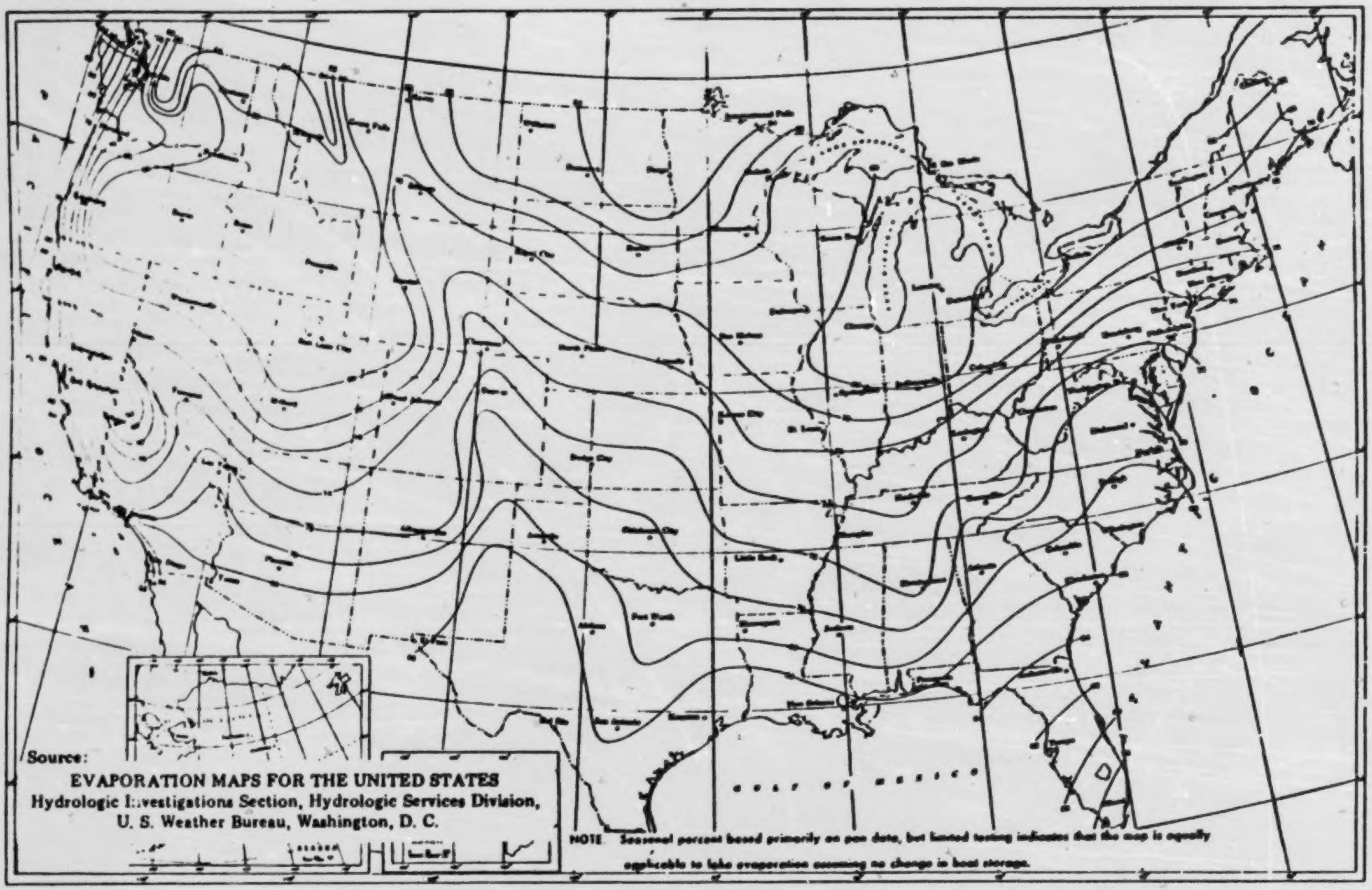
Based on period 1946-55

Fig. 44 Mean annual lake evaporation (in inches)



Source:
EVAPORATION MAPS FOR THE UNITED STATES
Hydrologic Investigations Section, Hydrologic Services Division,
U. S. Weather Bureau, Washington, D. C.

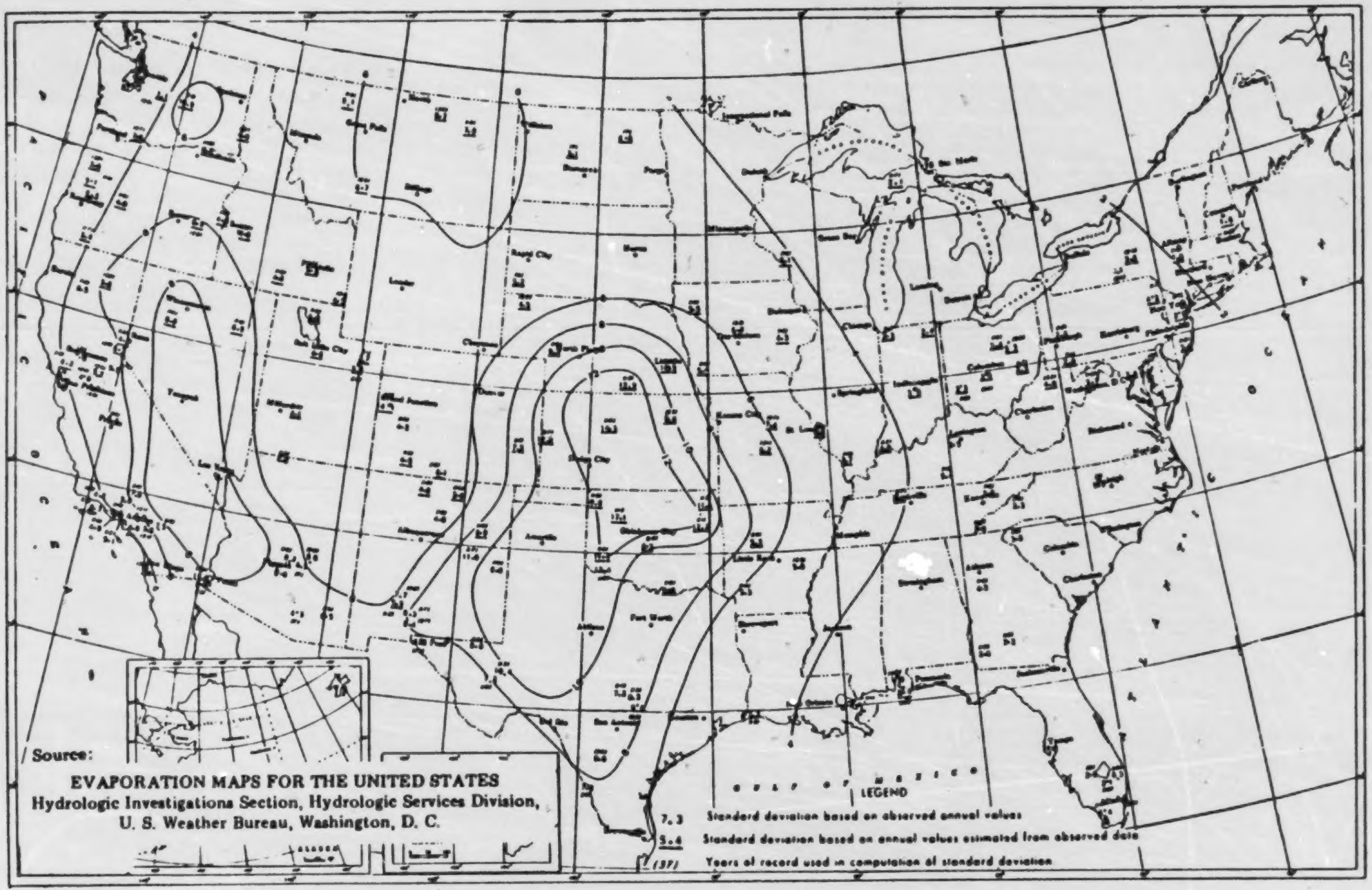
Fig. 45 Mean annual class A pan coefficient (in percent)



Source:
EVAPORATION MAPS FOR THE UNITED STATES
Hydrologic Investigations Section, Hydrologic Services Division,
U. S. Weather Bureau, Washington, D. C.

NOTE. Seasonal percent based primarily on pan data, but limited testing indicates that the map is equally applicable to lake evaporation assuming no change in heat storage.

Fig. 46 Mean May—October evaporation in percent of annual


GULF OF MEXICO
LEGEND
7.3 Standard deviation based on observed annual values
5.4 Standard deviation based on annual values estimated from observed data
(37) Years of record used in computation of standard deviation

Source:
EVAPORATION MAPS FOR THE UNITED STATES
Hydrologic Investigations Section, Hydrologic Services Division,
U. S. Weather Bureau, Washington, D. C.

Fig. 47 Standard deviation of annual class A pan evaporation (in inches)

APPENDIX C.

REQUESTS FOR SERVICES

The National Climatic Center may furnish special services for private clients under authority of an Act of Congress which permits the NCC to provide services at the expense of the requester. The amount the requester is charged in all cases is intended solely to defray the expenses incurred by the Government in satisfying his specific requirements to the best of its ability.

Unit costs have been established for reproduction or processing of data. The product can be in various forms, such as copies of microfilm, magnetic tapes, computer output in the form of tabulations, or other types of material. In the case of the programs discussed in this report, the station record must be serially complete and readily available in the NCC tape library. A day or two of missing record during a month is acceptable over the 20 to 25 year record, but care must be exercised to avoid processing stations with excessive missing record. Upon establishing that an adequate data base exists and costs agreed on, authorization for the NCC to proceed with the work may be made by letter or telephone. A copy of the product will be forwarded, usually within 3 to 4 weeks, along with an invoice. No advance payment is necessary, although private users who have a continuing need for climatological services may make advance deposits to cover the cost of their requirements as they arise. This procedure eliminates the need for separate invoices upon completion of each request. Further information about the programs may be obtained by contacting the Statistical Climatology Branch, National Climatic Center, Federal Building, Asheville, North Carolina 28801 (telephone 704-258-2850, ext. 319).

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT

Computer programs have been developed to estimate storage needs for Soil Treatment Systems from analyses of daily climatological data. One program uses a set of thresholds for temperature, precipitation and/or snow depth to estimate storage needs in colder regions.

A second program is designed for use in high rainfall regions where saturated soil, rather than severe weather, is the limiting condition. Climatological data for a 20- to 25-year period is examined for each case to produce a summary table. This table presents the mean, the standard deviation, the unbiased third moment about the mean, the coefficient of skewness and storage days for recurrence intervals of 5, 10, 25, and 50 years.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Climatology Effluents Cold-weather operations	Land application Estimating storage	4B 2C

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APPENDIX B

Irrigation Water Requirements (Excerpts)

The first 40 pages of Soil Conservation Service Technical Release No. 21 are reproduced here. This material includes a glossary of terms, a discussion of the Blaney-Criddle formula with modifications to compute short-term and seasonal consumptive water use, peak period calculation, effective rainfall, carryover soil moisture, groundwater contribution, and field application efficiency. These factors are combined to yield a net field irrigation requirement. Sample calculations illustrate the application of all these points to design problems.

The remainder of the Technical Release, not reproduced here, includes other factors which must be considered in a detailed irrigation system design, such as salt leaching water requirements, freeze protection, conveyance and storage losses, and operational losses. An appendix contains growth curves similar to Figures 1 and 2 for other crops.

U. S. Department of Agriculture
Soil Conservation Service
Engineering Division

Technical Release No. 21 (Rev. 2)
September, 1970
and (Rev. 1) February, 1967

IRRIGATION WATER REQUIREMENTS

Introduction

It is essential that the water requirements and consumptive use of water be known in irrigation planning for soil conservation and irrigation districts and for individual farms. Conservation of water supplies, as well as of soils, is of first importance in the agricultural economy. In basin-wide investigations of water utilization and in water conservation surveys, consumptive water requirement is one of the most important factors to be considered. There is an urgent need for information on irrigation requirements in connection with farm planning programs for areas where few data are available.

A knowledge of consumptive use is necessary in planning farm irrigation system layouts and improving irrigation practices. Irrigation and consumptive water requirement data are used more and more widely by water superintendents as well as state, federal, and other agencies responsible for the planning, construction, operation and maintenance of multiple-purpose projects and by those responsible for guiding and assisting farmers in the solution of their irrigation problems.

Scope

This release covers the procedures used to estimate irrigation water requirements on a farm or on a project. Irrigation application efficiencies are discussed briefly. More detailed information is presented in applicable chapters of Section 15 of the National Engineering Handbook. Procedures for measuring losses in existing farm distribution and project conveyance systems and for estimating losses in such systems as may be proposed are included. Irrigation water storage requirements may be estimated by use of the procedure contained in Technical Release No. 19.

Definition of Terms

Some of the terms used in this release are defined as follows:

Consumptive Use.

Consumptive use, often called evapo-transpiration, is the amount of water used by the vegetative growth of a given area in transpiration and building of plant tissue and that evaporated from adjacent soil or intercepted precipitation on the plant foliage in any specified time. If the unit of time is small, consumptive use is usually expressed as acre inches per acre or depth in inches, whereas, if the unit of time is large, such as a growing season or a 12-month period, it is usually expressed as acre feet per acre or depth in feet.

Consumptive Water Requirement.
The amount of water potentially required to meet the evapo-transpiration needs of vegetative areas so that plant production is not limited from lack of water.

Effective Rainfall.
Precipitation falling during the growing period of the crop that is available to meet the consumptive water requirements of crops. It does not include such precipitation as is lost to deep percolation below the root zone nor to surface runoff.

Consumptive Irrigation Requirement.
The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production.

Net Irrigation Requirement.
The depth of irrigation water, exclusive of precipitation, stored soil moisture, or ground water, that is required consumptively for crop production and required for other related uses. Such uses may include water required for leaching, frost protection, etc.

Peak Period Consumptive Use.
Peak period consumptive use is the average daily rate of use of a crop occurring during a period between normal irrigations when such rate of use is at a maximum.

Irrigation Efficiency.
The percentage of applied irrigation water that is stored in the soil and available for consumptive use by the crop. When the water is measured at the farm headgate, it is called farm-irrigation efficiency; when measured at the field, it is designated as field-irrigation efficiency; and when measured at the point of diversion, it may be called project-efficiency.

Irrigation Water Requirement.
The net irrigation water requirement divided by the irrigation efficiency.

Field Capacity.
The moisture percentage, on a dry weight basis, of a soil after rapid drainage has taken place following an application of water, provided there is no water table within capillary reach of the root zone. This moisture percentage usually is reached within two to four days after an irrigation, the time interval depending on the physical characteristics of the soil.

Wilting Point.
The wilting point is the moisture percentage, also on a dry weight basis, at which plants can no longer obtain sufficient moisture to satisfy moisture requirements and will wilt permanently unless moisture is added to the soil profile.

Carryover Soil Moisture.
Moisture stored in soils within root zone depths during the winter, at times when the crop is dormant, or before the crop is planted. This moisture is available to help meet the consumptive water needs of the crop.

Influence of Various Factors on Water Use

Many factors operate singly or in combination to influence the amounts of irrigation water consumed by plants. Their effects are not necessarily constant but may differ with locality and fluctuate from time to time. The more important influences are climate, water supply, and plant growth characteristics.

Precipitation.
The amount and rate of precipitation will have an effect on the amount of irrigation water consumptively used during any season. Under certain conditions, precipitation may be a series of frequent, light showers during the hot summer. Such showers may add little or nothing to the soil moisture for use by the plants through transpiration but do decrease the withdrawal from the stored moisture. The precipitation may be largely lost by evaporation directly from the surface of the plant foliage and from the land surface. Some of the precipitation from heavy storms may be lost by surface runoff. Where storms occur within a relatively short period after completion of an irrigation, a high percentage of precipitation is lost due to surface runoff, deep percolation or both. Other storms may be of such intensity and amount that a large percentage of their precipitation will enter the soil and become available for plant transpiration. Such a condition materially reduces the amount of irrigation water needed.

Temperature.
The rate of consumptive use of water by crops in any particular locality is probably affected more by temperature, which for long-time periods is a good measure of solar radiation, than by any other factor. Abnormally low temperatures may retard plant growth and unusually high temperatures may produce dormancy. Consumptive use may vary even in years of equal accumulated temperatures because of deviations from the normal seasonal distribution. Transpiration is influenced not only by temperature but also by the area of leaf surface and the physiologic needs of the plant, both of which are related to stage of maturity.

Growing Season.
The growing season, which is tied rather closely to temperature, has a major effect on the seasonal use of water by plants. It is frequently considered to be the period between killing frosts, but for many annual crops, it is shorter than the frost-free period, as such crops are usually planted after frosts are past and mature before they recur.

For most perennial crops, growth starts as soon as the maximum temperature stays well above the freezing point for an extended period of days, and continues throughout the season despite later freezes.

Sometimes growth persists after the first so-called killing frost in the fall. In the spring, and to less extent in the fall, daily minimum temperatures may fluctuate several degrees above and below 32° F. for several days before remaining generally above or below the freezing point. The hardier crops survive these fluctuations and continue unharmed during a few hours of subfreezing temperature. In fact, many hardy crops, especially grasses, may mature even though growing season temperatures repeatedly drop below freezing. Although the frost-free season may be used as a guide for estimating consumptive use, actual dates of planting and crop maturity are important in determining the consumptive irrigation requirements of the crops.

Latitude and Sunlight.
Because of the earth's movement and axial inclination, the hours of daylight during the summer are much greater in the higher latitudes than at the Equator. Since the sun is the source of all energy used in crop growth and evaporation of water, this longer day may allow plant transpiration to continue for a longer period each day and to produce an effect similar to that of lengthening the growing season.

Other Climatic Factors.
Other climatic factors that have an effect on the amount of irrigation water consumed by plants are as follows:

Humidity.--Evaporation and transpiration are accelerated on days of low humidity and slowed during periods of high humidity. If the average relatively humidity percentage is low during the growing season, a greater use of water by vegetation may be expected.

Wind movement.--Evaporation of water from land and plant surfaces takes place more rapidly when there is moving air than under calm air conditions. Hot, dry winds and other unusual wind conditions during the growing period will affect the amount of water consumptively used. However, there is a limit in the amount of water that can be utilized. As soon as the land surface is dry, evaporation practically stops and transpiration is limited by the ability of the plants to extract and convey the soil moisture through the plants.

Advection.--Crops grown in irrigated areas surrounded by large arid or semi-arid areas can receive additional energy for vaporization of water by advection. A high percentage of net solar radiation received in arid areas is used in heating the atmosphere. As this warm air mass moves over irrigated areas that are generally cooler, energy contained in the air as sensible heat can be used to evaporate water by vertical turbulent transfer. Thus an "oasis" effect is created. This evaporation of water by vertical turbulent transfer may cause a considerable increase in normal consumptive use in arid areas. It is not believed to be of significance in humid areas.

Stage of Plant Growth.
Other factors being equal, the stage of a crop's growth has a very

considerable influence on its consumptive-use rate. This is particularly true for annual crops which generally have three rather distinct stages of growth. These are (1) emergence and development of complete vegetative cover during which time the consumptive-use rate increases rapidly from a low value and approaches its maximum; (2) the period of maximum vegetative cover during which time the consumptive-use rate may be near or at its maximum if abundant soil moisture is available and (3) crop maturation where, for most crops, the consumptive-use rate begins to decrease. During the maturation period, the plant becomes the limiting factor in the transpiration rate.

Available Irrigation Water Supply.

All the above-mentioned factors influece the amount of water that potentially can be consumed in a given area. However, there are other factors that also cause important differences in the consumptive-use rates. Naturally, unless water is available from some source (precipitation, natural ground water, or irrigation), there can be no consumptive use. In those areas of the arid and semi-arid West where the major source is irrigation, both the quantity and seasonal distribution of the available supply will affect consumptive use. Where water is plentiful and cheap, there is a tendency for farmers to over-irrigate. If the soil surface is frequently wet and the resulting evaporation is high, the combined evaporation and transpiration or consumptive use may likewise increase. Also, under more optimum soil moisture conditions, yields of crops may be higher than average and more water consumed.

Quality of Water.

Some investigations have shown that, besides the quantity and seasonal distribution of the water supply, the quality of the water also has a minor effect on the consumptive use. Whether or not plants require more or less water, if the supply is highly saline may be debatable.

Soil Fertility.

If a soil is made more fertile through the application of manure or by some other means, the yields may be expected to increase with an accompanying increase in water use. However, this increase is so small that it is seldom considered when estimating consumptive use.

Estimating Consumptive Use

In areas for which few or no measurements of consumptive use are available, it is usually necessary to estimate consumptive use of crops from climatological data. For this purpose the Soil Conservation Service uses the Blaney-Criddle method with some modifications.

Blaney and Criddle found that the amount of water consumptively used by crops during their normal growing season was closely correlated with mean monthly temperatures and daylight hours. They developed coefficients that can be used to transpose the consumptive use data for a given area to other areas for which only climatological data are available. The net amount of irrigation water necessary to satisfy consumptive use is found by subtracting the effective precipitation from the consumptive water requirement during the growing or irrigation season.

As previously indicated, numerous factors must be taken into consideration if the consumptive use of water is to be determined accurately. Of the climatic factors, the effect of temperature and sunshine upon plant growth as measures of solar radiation is without doubt the most important. Temperature and precipitation records are more readily available than most other climatic data. Records of actual sunshine are not generally available, but the effect of sunshine is very important on the rate of plant growth and the amount of water plants will consume.

The effect of sunshine can be introduced by using the length of days during the crop-growing season at various latitudes. As an example, the length of the daytime at the Equator varies little throughout the year, whereas at 50° N. latitude, the length of the day in summer is much longer than in winter. Thus, at equal temperatures, photosynthesis can take place for several hours longer each June day at the north latitude than at the Equator. Crop growth and water consumption vary with the opportunity for photosynthesis.

The Blaney-Criddle procedure has generally given sufficiently accurate results when used for the purpose for which it was originally developed, that is for estimating seasonal consumptive use. However, the design of irrigation systems, distribution systems, and water storage facilities require that estimates of consumptive use be made for short-time periods of from 5 to 30 days. It has been found that the seasonal crop coefficients previously mentioned are not constant for consecutive short periods throughout the growing season of a crop. Thus it became necessary to make two modifications in the original procedure in order to obtain reasonably accurate estimates of short-period consumptive use.

One modification requires the use of climatic coefficients that are directly related to the mean air temperature for each of the consecutive short periods which constitute the growing season. The other requires the use of coefficients which reflect the influence of the crop growth stages on consumptive-use rates. Both of these modifications are explained in more detail in later paragraphs.

The Blaney-Criddle Formula

Disregarding many influencing factors, consumptive use varies with the temperature, length of day, and available moisture regardless of its source (precipitation, irrigation water, or natural ground water.) Multiplying the mean monthly temperature (t) by the possible monthly percentage of daytime hours of the year (p) gives a monthly consumptive-use factor (f). It is assumed that crop consumptive use varies directly with this factor when an ample water supply is available. Expressed mathematically $u = kf$ and $U = \text{sum of } kf = KF$ where,

U = Consumptive use of the crop in inches for the growing season.

K = Empirical consumptive-use crop coefficient for the growing season. This coefficient varies with the different crops being irrigated.

F = Sum of the monthly consumptive-use factors for the growing season (sum of the products of mean monthly temperature and monthly percentage of daylight hours of the year).

u = Monthly consumptive use of the crop in inches.

k = Empirical consumptive-use crop coefficient for a month (also varies by crops).

f = Monthly consumptive-use factor (product of mean monthly temperature and monthly percentage of daylight hours of the year).

$f = \frac{t \times p}{100}$, where

t = Mean monthly air temperature in degrees Fahrenheit.

p = Monthly percentage of daylight hours in the year. Values of (p) for latitudes 0 to 65 degrees north of the Equator are shown in Table 1.

Note: Values of (t), (p), (f), and (k), can also be made to apply to periods of less than a month.

Following are modifications made in the original formula:

$k = k_t \times k_c$, where,

k_t = A climatic coefficient which is related to the mean air temperature (t).

$k_t = .0173t - .314$. Values of k_t for mean air temperatures from 36 to 100 degrees are shown in table 4.

k_c = A coefficient reflecting the growth stage of the crop. Values are obtained from crop growth stage coefficient curves such as those shown in figures 1 and 2.

The consumptive-use factor (F) may be computed for areas for which monthly temperature records are available, if the percentage of hours that is shown in table 1 is used. Then, the total crop consumptive use (U) is obtained by multiplying (F) by the empirical consumptive-use crop coefficient (K). This relationship allows the computation of seasonal consumptive use at any location for those crops for which values of (K) have been experimentally established or can be estimated.

Seasonal Comsumptive-Use Coefficients.

Consumptive-use coefficients (K) have been determined experimentally at numerous localities for most crops grown in the western states. Consumptive-use values (U) were measured and these data were correlated with temperature and growing season. Crop consumptive-use coefficients (K) were then computed by the formula, $K = U/F$. The computed coefficients varied somewhat because of the diverse conditions (such as soils, water supply, and methods) under which the studies were conducted. These coefficients were adjusted where necessary after the data were analyzed. The resulting coefficients are believed to be suitable for use under normal conditions.

While only very limited investigations of consumptive use have been made in the eastern or humid-area states, studies made thus far fail to indicate that there should be any great difference between the seasonal consumptive-use coefficients used there and those used in the western states.

Table 2 shows the values of seasonal consumptive-use crop coefficients currently proposed by Blaney and Criddle for most irrigated crops. It will be noted that ranges in the values of these coefficients are shown. These, however, are not all inclusive limits. In some circumstances K values may be either higher or lower than shown.

Monthly or Short-Time Consumptive-Use Coefficients.

Although seasonal coefficients (K) as reported by various investigators show some variation for the same crops, monthly or short-time coefficients (k) show even greater variation. These great variations are influenced by a number of factors which must be given consideration when computing or estimating short-time coefficients. Although these factors are numerous, the most important are temperature and the growth stage of the crop. These factors are discussed in succeeding paragraphs.

Growing Season.

In utilizing the Blaney-Criddle formula for computing seasonal requirements, the potential growing season for the various crops is normally considered to extend from frost to frost or from the last killing frost in the spring to the end of a definite period of time thereafter. For most crops, this is adequate for seasonal use estimates, but a refinement is necessary to more precisely define the growing season when monthly or short-time use estimates are required. In many areas, records are available from which planting, harvesting and growth dates can be determined. These should be used where possible. In other areas, temperature data may be helpful for estimating these dates. Table 3 contains some guides which may be helpful in determining these dates.

Since the spring frost date corresponds very nearly with a mean temperature of 55 degrees, it is obvious that many of the common crops use appreciable amounts of water prior to the last frost in the spring and may continue to use water after the first frost in the fall.

Climatic Coefficient (k_t).

While it is recognized that a number of climatological factors have an

Table 1.--Monthly percentage of daytime hours (p) of the year for latitudes 18° to 65° north of the equator.

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°	3.52	5.13	7.96	9.97	12.72	14.15	13.59	11.18	8.55	6.53	4.08	2.62
64°	3.81	5.27	8.00	9.92	12.50	13.63	13.26	11.08	8.56	6.63	4.32	3.02
63°	4.07	5.39	8.04	9.86	12.29	13.24	12.97	10.97	8.56	6.73	4.52	3.36
62°	4.31	5.49	8.07	9.80	12.11	12.92	12.73	10.87	8.55	6.80	4.70	3.65
61°	4.51	5.58	8.09	9.74	11.94	12.66	12.51	10.77	8.55	6.88	4.86	3.91
60°	4.70	5.67	8.11	9.69	11.78	12.41	12.31	10.68	8.54	6.95	5.02	4.14
59°	4.86	5.76	8.13	9.64	11.64	12.19	12.13	10.60	8.53	7.00	5.17	4.35
58°	5.02	5.84	8.14	9.59	11.50	12.00	11.96	10.52	8.53	7.06	5.30	4.54
57°	5.17	5.91	8.15	9.53	11.38	11.83	11.81	10.44	8.52	7.13	5.42	4.71
56°	5.31	5.98	8.17	9.48	11.26	11.68	11.67	10.36	8.52	7.18	5.52	4.87
55°	5.44	6.04	8.18	9.44	11.15	11.53	11.54	10.29	8.51	7.23	5.63	5.02
54°	5.56	6.10	8.19	9.40	11.04	11.39	11.42	10.22	8.50	7.28	5.74	5.16
53°	5.68	6.16	8.20	9.36	10.94	11.26	11.30	10.16	8.49	7.32	5.83	5.30
52°	5.79	6.22	8.21	9.32	10.85	11.14	11.19	10.10	8.48	7.36	5.92	5.42
51°	5.89	6.27	8.23	9.28	10.76	11.02	11.09	10.05	8.47	7.40	6.00	5.54
50°	5.99	6.32	8.24	9.24	10.68	10.92	10.99	9.99	8.46	7.44	6.08	5.65
49°	6.08	6.36	8.25	9.20	10.60	10.82	10.90	9.94	8.46	7.48	6.16	5.75
48°	6.17	6.41	8.26	9.17	10.52	10.72	10.81	9.89	8.45	7.51	6.24	5.85
47°	6.25	6.45	8.27	9.14	10.45	10.63	10.73	9.84	8.44	7.54	6.31	5.95
46°	6.33	6.50	8.28	9.11	10.38	10.53	10.65	9.79	8.43	7.58	6.37	6.05
45°	6.40	6.54	8.29	9.08	10.31	10.46	10.57	9.75	8.42	7.61	6.43	6.14
44°	6.48	6.57	8.29	9.05	10.25	10.39	10.49	9.71	8.41	7.64	6.50	6.22
43°	6.55	6.61	8.30	9.02	10.19	10.31	10.42	9.66	8.40	7.67	6.56	6.31
42°	6.61	6.65	8.30	8.99	10.13	10.24	10.35	9.62	8.40	7.70	6.62	6.39
41°	6.68	6.68	8.31	8.96	10.07	10.16	10.29	9.59	8.39	7.72	6.68	6.47
40°	6.75	6.72	8.32	8.93	10.01	10.09	10.22	9.55	8.39	7.75	6.73	6.54
39°	6.81	6.75	8.33	8.91	9.95	10.03	10.16	9.51	8.38	7.78	6.78	6.61
38°	6.87	6.79	8.33	8.89	9.90	9.96	10.11	9.47	8.37	7.80	6.83	6.68
37°	6.92	6.82	8.34	8.87	9.85	9.89	10.05	9.44	8.37	7.83	6.88	6.74
36°	6.98	6.85	8.35	8.85	9.80	9.82	9.99	9.41	8.36	7.85	6.93	6.81
35°	7.04	6.88	8.35	8.82	9.76	9.76	9.93	9.37	8.36	7.88	6.98	6.87
34°	7.10	6.91	8.35	8.80	9.71	9.71	9.88	9.34	8.35	7.90	7.02	6.93
33°	7.15	6.94	8.36	8.77	9.67	9.65	9.83	9.31	8.35	7.92	7.06	6.99
32°	7.20	6.97	8.36	8.75	9.62	9.60	9.77	9.28	8.34	7.95	7.11	7.05
31°	7.25	6.99	8.36	8.73	9.58	9.55	9.72	9.24	8.34	7.97	7.16	7.11
30°	7.31	7.02	8.37	8.71	9.54	9.49	9.67	9.21	8.33	7.99	7.20	7.16
29°	7.35	7.05	8.37	8.69	9.50	9.44	9.62	9.19	8.33	8.00	7.24	7.22
28°	7.40	7.07	8.37	8.67	9.46	9.39	9.58	9.17	8.32	8.02	7.28	7.27
27°	7.44	7.10	8.38	8.66	9.41	9.34	9.53	9.14	8.32	8.04	7.32	7.32
26°	7.49	7.12	8.38	8.64	9.37	9.29	9.49	9.11	8.32	8.06	7.36	7.37
25°	7.54	7.14	8.39	8.62	9.33	9.24	9.45	9.08	8.31	8.08	7.40	7.42
24°	7.58	7.16	8.39	8.60	9.30	9.19	9.40	9.06	8.31	8.10	7.44	7.47
23°	7.62	7.19	8.40	8.58	9.26	9.15	9.36	9.04	8.30	8.12	7.47	7.51
22°	7.67	7.21	8.40	8.56	9.22	9.11	9.32	9.01	8.30	8.13	7.51	7.56
21°	7.71	7.24	8.41	8.55	9.18	9.06	9.28	8.98	8.29	8.15	7.55	7.60
20°	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
19°	7.79	7.28	8.41	8.51	9.12	8.97	9.20	8.93	8.29	8.19	7.61	7.70
18°	7.83	7.31	8.41	8.50	9.08	8.93	9.16	8.90	8.29	8.20	7.65	7.74

Table 1.--Monthly percentage of daytime hours (p) of the year for latitudes 0° to 20° north of the equator

Latitude North	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
20°	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
19°	7.79	7.28	8.41	8.51	9.12	8.97	9.20	8.93	8.29	8.19	7.61	7.70
18°	7.83	7.31	8.41	8.50	9.08	8.93	9.16	8.90	8.29	8.20	7.65	7.74
17°	7.87	7.33	8.42	8.48	9.04	8.89	9.12	8.88	8.28	8.22	7.68	7.79
16°	7.91	7.35	8.42	8.47	9.01	8.85	9.08	8.85	8.28	8.23	7.72	7.83
15°	7.94	7.37	8.43	8.45	8.98	8.81	9.04	8.83	8.27	8.25	7.75	7.88
14°	7.98	7.39	8.43	8.43	8.94	8.77	9.00	8.80	8.27	8.27	7.79	7.93
13°	8.02	7.41	8.43	8.42	8.91	8.73	8.96	8.78	8.26	8.29	7.82	7.97
12°	8.06	7.43	8.44	8.40	8.87	8.69	8.92	8.76	8.26	8.31	7.85	8.01
11°	8.10	7.45	8.44	8.39	8.84	8.65	8.88	8.73	8.26	8.33	7.88	8.05
10°	8.14	7.47	8.45	8.37	8.81	8.61	8.85	8.71	8.25	8.34	7.91	8.09
9°	8.18	7.49	8.45	8.35	8.77	8.57	8.81	8.68	8.25	8.36	7.95	8.14
8°	8.21	7.51	8.45	8.34	8.74	8.53	8.78	8.66	8.25	8.37	7.98	8.18
7°	8.25	7.53	8.46	8.32	8.71	8.49	8.74	8.64	8.25	8.38	8.01	8.22
6°	8.28	7.55	8.46	8.31	8.68	8.45	8.71	8.62	8.24	8.40	8.04	8.26
5°	8.32	7.57	8.47	8.29	8.65	8.41	8.67	8.60	8.24	8.41	8.07	8.30
4°	8.36	7.59	8.47	8.28	8.62	8.37	8.64	8.57	8.23	8.43	8.10	8.34
3°	8.40	7.61	8.48	8.26	8.58	8.33	8.60	8.55	8.23	8.45	8.13	8.38
2°	8.43	7.63	8.49	8.25	8.55	8.29	8.57	8.53	8.22	8.46	8.16	8.42
1°	8.47	7.65	8.49	8.23	8.52	8.25	8.53	8.51	8.22	8.48	8.19	8.46
0°	8.50	7.67	8.49	8.22	8.49	8.22	8.50	8.49	8.21	8.49	8.22	8.50

Table 2.--Seasonal consumptive-use crop coefficients (K) for irrigated crops

Crop	Length of Normal Growing Season or Period 1/	Consumptive-use coefficient (K) 2/
Alfalfa	Between frosts	0.80 to 0.90
Bananas	Full year	.80 to 1.00
Beans	3 months	.60 to .70
Cocoa	Full year	.70 to .80
Coffee	Full year	.70 to .80
Corn (Maize)	4 months	.75 to .85
Cotton	7 months	.60 to .70
Dates	Full year	.65 to .80
Flax	7 to 8 months	.70 to .80
Grains, small	3 months	.75 to .85
Grain, sorghums	4 to 5 months	.70 to .80
Oilseeds	3 to 5 months	.65 to .75
Orchard crops:		
Avocado	Full year	.50 to .55
Grapefruit	Full year	.55 to .65
Orange and lemon	Full year	.45 to .55
Walnuts	Between frosts	.60 to .70
Deciduous	Between frosts	.60 to .70
Pasture crops:		
Grass	Between frosts	.75 to .85
Ladino whiteclover	Between frosts	.80 to .85
Potatoes	3 to 5 months	.65 to .75
Rice	3 to 5 months	1.00 to 1.10
Soybeans	140 days	.65 to .70
Sugar beet	6 months	.65 to .75
Sugarcane	Full year	.80 to .90
Tobacco	4 months	.70 to .80
Tomatoes	4 months	.65 to .70
Truck crops, small	2 to 4 months	.60 to .70
Vineyard	5 to 7 months	.50 to .60

1/ Length of season depends largely on variety and time of year when the crop is grown. Annual crops grown during the winter period may take much longer than if grown in the summertime.

2/ The lower values of (K) for use in the Blaney-Criddle formula, U = KF, are for the more humid areas, and the higher values are for the more arid climates.

effect on consumptive use by crops, seldom is complete climatological data on relative humidity, wind movement, sunshine hours, pan evaporation, etc., available for a specific site. Thus it is necessary to rely on records of temperature which are widely available.

In 1954 J. T. Phelan attempted to correlate the monthly consumptive-use coefficient (k) with the mean monthly temperature (t). It was noted that a loop effect occurred in the plotted points; the computed values of (k) were higher in the spring than in the fall for the same temperature. The effects of this loop were later corrected by the development of a crop growth stage coefficient (k_c). The relationship between (k) and (t) was adopted for computing values of (k_t), the temperature coefficient. This relationship is expressed as $k_t = .0173_t - .314$. Table 4 gives values of (k_t) for temperatures ranging from 36 to 100 degrees Fahrenheit.

Crop Growth Stage Coefficients (k_c).

As previously stated, another factor which causes consumptive use to vary widely throughout the growing season is the plant itself. Stage of growth is a primary variable that must be recognized since it is obvious that plants in the rapid growth stage will use water at a more rapid rate than will new seedlings. It is also obvious that these variations in consumptive use throughout the growing season will be greater for annual crops than for perennial crops such as alfalfa, permanent pasture grasses and orchards.

In order to recognize these variations in consumptive use, crop growth stage coefficients (k_c) have been introduced into the formula. Values of these coefficients are calculated from research data. When values of (k_c) are plotted against time or stage of growth, curves similar to those shown in figures 1 and 2 will result. Such curves are used to obtain values of (k_c) which, when used with appropriate values of (k_t), will permit a determination of values of monthly or short-time consumptive-use coefficients (k).

It is also recognized that value of (k_c) might, to some extent, be influenced by factors other than the characteristics of the plant itself. For this reason, it is not expected that these curves can be used universally. They should, however, be valid over a considerable area and certainly should be of value in areas where no measured consumptive-use data is available.

With annual crops, such as corn, values of the coefficient (k_c) are best plotted as a function of a percentage of the growing season. Figure 1 shows the suggested values of (k_c) for corn.

With perennial crops, values of the coefficient (k_c) are usually best plotted on a monthly basis. Figure 2 shows the plotting of such values for alfalfa. Crop growth stage coefficient curves for all crops for which data are available are contained in the appendix.

Table 3.--A guide for determining planting dates, maturity dates and lengths of growing seasons as related to mean air temperature

Crop	Earliest moisture-use or planting date as related to mean air temperature	Latest moisture-use or maturing date as related to mean air temperature	Growing Season Days
Perennial Crops			
Alfalfa	50° mean temp.	28° frost	Variable
Grasses, cool	45° mean temp.	45° mean temp.	Variable
Orchards, decid.	50° mean temp.	45° mean temp.	Variable
Grapes	55° mean temp.	50° mean temp.	Variable
Annual Crops			
Beans, dry	60° mean temp.	32° frost	90 - 100
Corn	55° mean temp.	32° frost	140 - Max.
Cotton	62° mean temp.	32° frost	240 - Max.
Grain, spring	45° mean temp.	32° frost	130 - Max.
Potatoes, late	60° mean temp.	32° frost	130 - Max.
Sorghum, grain	60° mean temp.	32° frost	130 - Max.
Sugar beets	28° frost	28° frost	180 - Max.
Wheat, winter			
(Fall season)		45° mean temp.	
(Spring season)	45° mean temp.		

Assumptions in Applying the Formula.

In order to apply results of a consumptive-use-of-water study in one area to other areas, it is usually necessary to make certain assumptions. As previously indicated, if sufficient basic information is available locally, such actual data should be used. But rarely are all needed data known in sufficient detail. Where necessary information is lacking, the following assumptions must be made in applying the consumptive-use formula to transfer data between areas:

1. Seasonal consumptive use (U) of water varies directly with the consumptive-use factor (F).

2. Crop growth and yields are not limited by inadequate water at any time during the growing season.

3. Growing periods for alfalfa, pasture, orchard crops, and "natural" vegetation, although usually extending beyond the frost-free periods, are usually indicated by such periods. Yields of crops dependent only upon vegetative growth vary with the length of the growing period.

Application to Specific Areas.

The application of the Blaney-Criddle formula to specific areas can best be illustrated by examples. Two have been chosen for this purpose. The first is an annual crop, corn, grown in a humid area, Raleigh, North Carolina. The second is a perennial crop, alfalfa, grown in an arid area, Denver, Colorado.

Corn at Raleigh, N. C.--The procedure for estimating the average daily, monthly and seasonal consumptive use by corn at this location is shown in Sample Calculation No. 1. The average length of the growing season for corn grown in the vicinity of Raleigh is 120 days beginning about April 20.

The estimate is made on a monthly basis, the months and fractions thereof being shown in column 1. The midpoint date for each month or fraction is shown in column 2. The accumulated number of days from the planting date, April 20, to the midpoint of each month or period is shown in column 3. The percentage of the 120-day growing season represented by these midpoint dates is shown in column 4. Thus Col. 4 = Col. 3 ÷ 120.

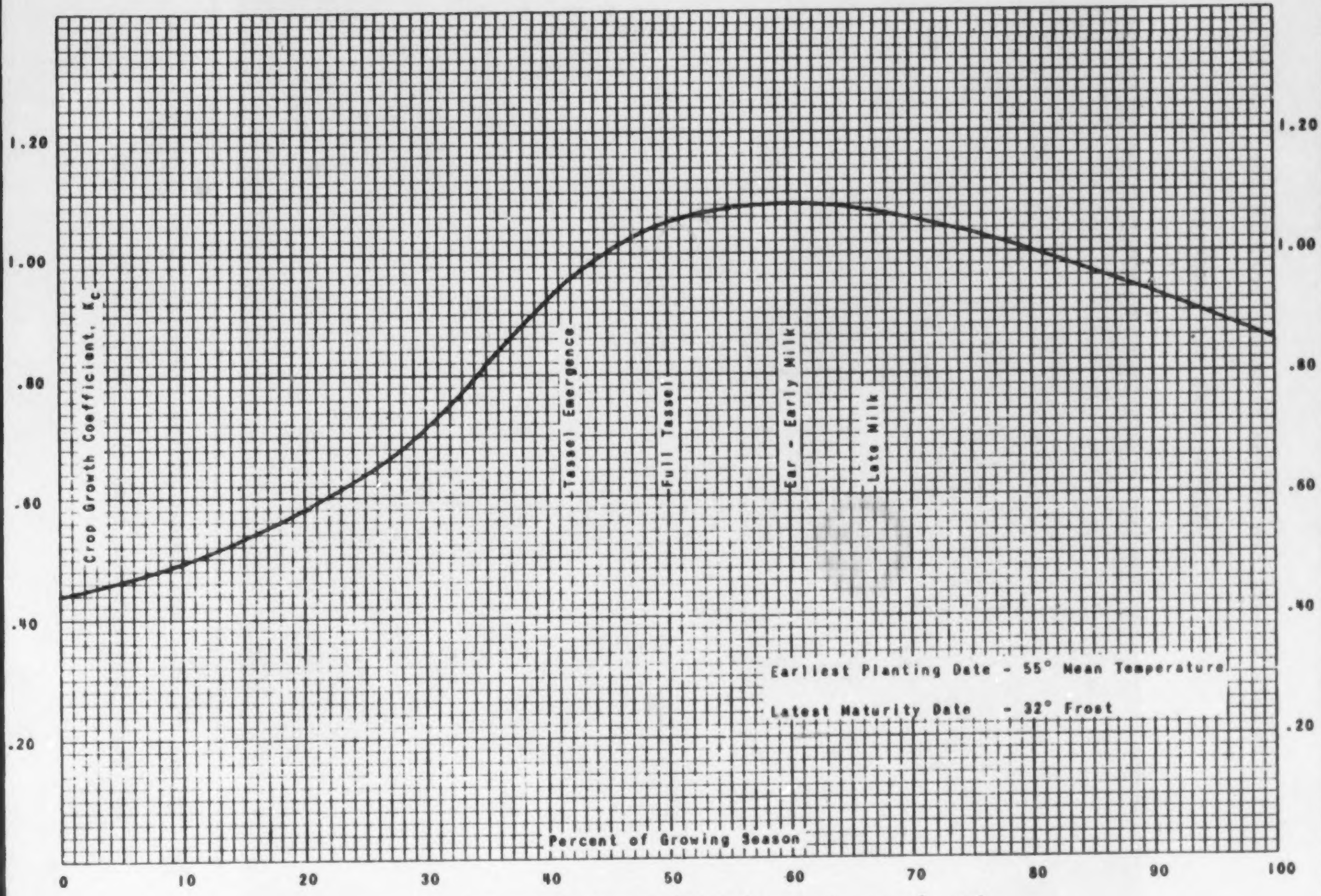
Mean monthly air temperature values, shown in column 5, are taken from Weather Bureau records. The mean temperature is assumed to occur on the 15th day of each month. The mean air temperature for a part of a month can be obtained mathematically or graphically by assuming that the increase or decrease in temperature between the 15th day of any consecutive month is a straight-line relationship. For example, at Raleigh, the mean monthly air temperature for April is 60.6° and that

Table 4.--Values of the climatic coefficient, k_t, 1/ for various mean air temperature, t.

t °F	k_t	t °F	k_t	t °F	k_t
36	.31	61	.74	86	1.17
37	.33	62	.76	87	1.19
38	.34	63	.78	88	1.21
39	.36	64	.79	89	1.23
40	.38	65	.81	90	1.24
41	.40	66	.83	91	1.26
42	.41	67	.85	92	1.28
43	.43	68	.86	93	1.30
44	.45	69	.88	94	1.31
45	.46	70	.90	95	1.33
46	.48	71	.91	96	1.35
47	.50	72	.93	97	1.36
48	.52	73	.95	98	1.38
49	.53	74	.97	99	1.40
50	.55	75	.98	100	1.42
51	.57	76	1.00		
52	.59	77	1.02		
53	.60	78	1.04		
54	.62	79	1.05		
55	.64	80	1.07		
56	.66	81	1.09		
57	.67	82	1.11		
58	.69	83	1.12		
59	.71	84	1.14		
60	.72	85	1.16		

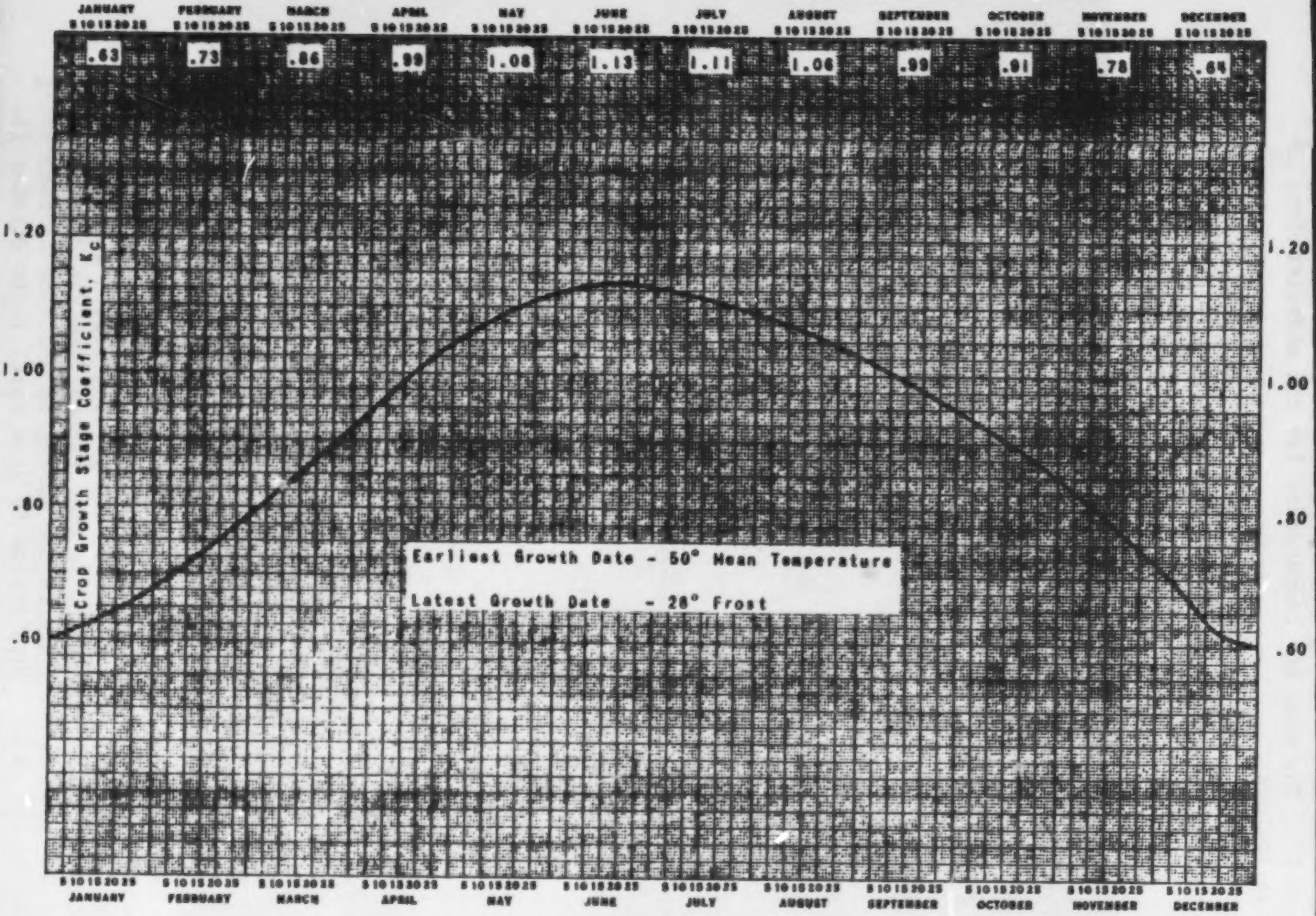
1/ Values of (k_t) are based on the formula, $k_t = .0173\ t - .314$

for mean temperatures less than 36°, use $k_t = .300$.



Crop growth stage coefficient curve for corn (grain)

Curve No. 1



Earliest Growth Date - 50° Mean Temperature

Latest Growth Date - 28° Frost

Crop growth stage coefficient curve for alfalfa

Curve No. 2

for May is 69.2°. The mean air temperature for the midpoint date is calculated as follows:

$$60.6° + \frac{10 \text{ days } (69.2° - 60.6°)}{30 \text{ days}} = 63.5°$$

Raleigh is located at Latitude 35° - 47' N. The monthly percentages of daylight hours, shown in column 6, are taken from table 1. For parts of a month the values of these percentages can be obtained in a similar manner as described for mean air temperatures. For example, at Raleigh, the monthly percentage of daylight hours for April is 8.84 and that for May is 9.79. For the period April 20 through April 30, the monthly percentage of daylight hours is calculated as follows:

$$\left[8.84\% + \frac{10 \text{ days } (9.79\% - 8.84\%)}{30 \text{ days}}\right] \frac{10 \text{ days}}{30 \text{ days}} = 3.05\%$$

The values of consumptive use factors (f) shown in column 7 are the product of (t) and (p) divided by 100. Values of the climatic coefficient (k_t), shown in column 8, are taken from table 4. Values of the crop growth stage coefficient (k_c), shown in column 9, are taken from the curve shown in figure 1. The values of the monthly consumptive-use coefficient (k), shown in column 10, are the product of (k_t) and (k_c). Values of monthly consumptive use (u), shown in column 11, are the product of values of (k) and (f). The average daily rates of consumptive use shown in column 12 are the monthly values of (u) (column 11) divided by the number of days in the month.

At this point the computed value of the seasonal consumptive-use coefficient (K) should be determined. This is done by totaling column 11 to obtain the seasonal consumptive-use value, $U = \Sigma u$, and by totaling column 7 to obtain the seasonal consumptive use factor, $F = \Sigma f$. The value of the seasonal consumptive-use coefficient (K), shown at the bottom of column 10, is then obtained by dividing the seasonal value of (U) by the seasonal value of (F). If the resulting value of (K) falls within the range of values for corn shown in table 2, the calculations may be assumed to have provided a reasonable estimate of consumptive use. If the resulting value of (K) falls outside the range shown in table 2, an adjustment of the crop growth stage coefficient curve may be indicated. In such cases, a qualified irrigation engineer or specialist should be consulted.

Alfalfa at Denver, Colo.--The procedure for estimating the average daily, monthly and seasonal consumptive use by alfalfa in this location is shown in Sample Calculation No. 2. The growing season for alfalfa grown near Denver is considered to be that period from the date corresponding to 50° mean temperature in the spring to the date corresponding to 28° frost in the fall. This period is from April 24 to October 25.

The procedure illustrated by Sample Calculation No. 2 is the same as that heretofore described for corn and illustrated by Sample Calculation

No. 1. The values of the crop growth stage coefficient, (k_c), shown in column 8 are taken from the curve for alfalfa shown in figure 2.

Peak Period Consumptive Use

Information on peak period rates of consumptive use is needed to properly design irrigation systems. It is used to determine the minimum capacity requirements of main and lateral canals, pipelines, and other water conveyance or control structures. The peak period rates of water use by crops also influence the administration of streams and reservoirs from which irrigation water supplies are obtained.

In irrigation project design, the peak period of consumptive use is the period during which the weighted average daily rate of consumptive use of the various crops grown in the project area is at a maximum. Different crops may have their peak rates of use at different times. Therefore, some crops may not be using water at their maximum rate during the project peak period. In fact, some of the crops may not even be grown during this period.

Factors Influencing Peak Period Use Rates.

While other factors may have a minor influence on peak period rates of consumptive use, peak period air temperature and net depth of irrigation application have the greatest influence.

Temperature.--An analysis of daily mean air temperature records for any month at any location will show that the mean temperature for the warmest consecutive 5-day period will be greater than that for the warmest 10-day period. Likewise, the mean temperature for the warmest consecutive 10-day period will be greater than that for the warmest 15-day period, and so on. All will be greater than the mean monthly temperature. Since consumptive use, as estimated by the Blaney-Criddle formula, is directly related to air temperature, it is obvious that the shorter the peak period is in days, the greater will be the mean temperature and therefore the greater will be the consumptive-use rate.

Net irrigation application.--The length of the peak period is that number of days in which the normal net irrigation application will last under the peak rate of use for the period. Thus smaller net irrigation applications will last for smaller periods of time and, as shown above, will result in greater peak period-use rates. Conversely, higher net irrigation applications will result in lower peak period-use rates.

Table 5 shows peak-period average daily consumptive-use rates as related to estimated monthly use and net irrigation application. As an illustration of the use of this table, the case of alfalfa irrigated near Denver may be used. From Sample Calculation No. 2, it will be noted that the peak-use month is July and that the average consumptive use for that month is 7.8 inches. From the Colorado irrigation guide, it

Sample Calculation No. 1.--Estimate of average daily, monthly and seasonal consumptive-use

by

Corn at Raleigh, North Carolina

(Harvested for grain)

Lat. 35° 47' North

(1) Month or Period	(2) Midpoint of Period	(3) Accum. Days to Midpoint	(4) Percent of Growing Season	(5) Mean Air Temp. t. ° F.	(6) Daylight Hours p. Percent	(7) Cons. Use Factor f.	(8) Climatic Coeff. k_t	(9) Growth Stage Coeff. k_c	(10) Cons. Use Coeff. k	(11) Monthly Cons. Use u. Inches	(12) Daily Cons. Use u. In./Day
Apr. 20											
	Apr. 25	5	4.2	63.5	3.05	1.94	.79	.46	.36	.70	.070
May											
	May 15	25	20.8	69.2	9.79	6.77	.88	.59	.52	3.52	.114
June											
	June 15	56	46.7	76.9	9.81	7.54	1.02	1.02	1.04	7.84	.261
July											
	July 15	86	71.7	79.4	9.98	7.92	1.06	1.05	1.11	8.79	.284
Aug.											
	Aug. 9	111	92.5	78.3	5.52	4.32	1.04	.91	.95	4.10	.228
Aug. 18											
Season Totals						28.49			.88	24.95	

Sample Calculation No. 2.--Estimate of average, daily, monthly and seasonal consumptive-use by Alfalfa at Denver, Colorado

Lat. 39° 40' North

(1) Month or Period	(2) Midpoint of Period	(3) Days in Period	(4) Mean Air Temp. t. ° F.	(5) Daylight Hours p. Percent	(6) Cons. Use Factor f	(7) Climatic Coeff. k_t	(8) Growth Stage Coeff. k_c	(9) Cons. Use Coeff. k	(10) Monthly Cons. Use u Inches	(11) Daily Cons. Use u In./Day
Apr. 24	Apr. 27	6	51.1	1.87	.96	.57	1.03	.59	.57	.095
May	May 15	31	56.3	9.99	5.62	.66	1.08	.71	3.99	.129
June	June 15	30	66.4	10.07	6.69	.84	1.13	.95	6.36	.212
July	July 15	31	72.8	10.20	7.43	.95	1.11	1.05	7.80	.252
Aug.	Aug. 15	31	71.3	9.54	6.80	.92	1.06	.98	6.66	.215
Sept.	Sept. 15	30	62.7	8.39	5.26	.77	.99	.76	4.00	.133
Oct.	Oct. 12	25	53.5	6.31	3.38	.61	.91	.56	1.89	.076
Oct. 25										
Season Totals					36.14			.87	31.27	

is determined that the net irrigation application is 4.2 inches. Thus, by interpolation from the table, the peak-period use rate is found to be 0.28 inch per day.

A suggested procedure for using table 5 to estimate project peak period consumptive-use requirements is outlined below and is illustrated by Sample Calculation No. 3.

1. Determine the net irrigation applications (I) required for the crops in the project area.

2. Determine the monthly consumptive-use rate (u_m) for each crop in the project area for the month of greatest overall water use. (Note that if some crop is using water for only a portion of the month, its rate of use must be computed by dividing the estimated requirement by the fraction of the month when water is used).

3. From table 5, using appropriate values of (I) and (u_m), determine the peak period consumptive-use rate (u_p) for each of the three crops.

4. Using the crop and soil distribution patterns established for the project, compute the weighted peak period consumptive-use rate for the project.

Effective Rainfall

Effective rainfall supplies a portion of the consumptive use by crops. It may be a nearly insignificant portion in arid areas such as the Salt River Valley of Arizona or it may be a major portion in humid areas such as the Atlantic Coastal Plain of the Carolinas. The engineer engaged in estimating irrigation water requirements of a crop is confronted with the problem of determining what portion of total consumptive use will be furnished by effective rainfall and what portion will have to be supplied by irrigation. Since there are no records of effective rainfall available, it is necessary to utilize total rainfall records and estimate the portion of total rainfall that is effective. A procedure for doing this is described in succeeding paragraphs.

Factors Influencing Rainfall Effectiveness.

Total rainfall.--In arid areas where total growing season precipitation is light, the moisture level in the soil profile at the time precipitation occurs is usually such that almost all of it enters the soil profile and becomes available for consumptive use. Losses due to surface runoff or to percolation below the crop root zone are usually negligible. Thus the effectiveness of rainfall in these areas is relatively high.

In humid areas, storms of large magnitude and high intensity occur frequently during the growing season. These storms often produce water in excess of that which can be stored in the soil profile for consumptive

Table 5.--Peak period average daily consumptive use rates (u_p) as related to estimated actual monthly use (u_m)

Net Irrigation Application I (Inches)	Computed Peak Monthly Consumptive Use Rate (u_m) in Inches [1]																
	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0
	Peak Period Daily Use Rate (u_p) in Inches per Day																
1.0	.15	.18	.20	.22	.24	.26	.28	.31	.33	.35	.37	.40	.42	.44	.46	.49	.51
1.5	.15	.17	.19	.21	.23	.25	.27	.29	.32	.34	.36	.38	.41	.43	.45	.47	.50
2.0	.15	.16	.18	.20	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46	.48
2.5	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.39	.41	.43	.45	.47
3.0	.14	.16	.18	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44	.46
3.5	.14	.16	.18	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.44	.46
4.0	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
4.5	.14	.15	.17	.19	.21	.23	.25	.27	.29	.31	.33	.35	.37	.39	.41	.43	.45
5.0	.13	.15	.17	.19	.21	.23	.25	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
5.5	.13	.15	.17	.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.42	.44
6.0	.13	.15	.17	.19	.20	.22	.24	.26	.28	.30	.32	.34	.36	.38	.40	.41	.43

[1] Based on the formula $u_p = 0.034\ u_m^{1.09}\ I^{-.09}$ where
u_p = Average daily peak period consumptive use in inches.
u_m = Average consumptive use for the peak month in inches.
I = Net irrigation application in inches.

Sample Calculation No. 3.--Estimate of project peak consumptive use rates for a project near Boise, Idaho

			Soil Mapping Units		
Item		Unit	1 M 3	1 S 6	Total
Soil Areas		Acres	930	570	1500
		Percent	62	38	100
Available Moisture Holding Capacity		In./ft.	2.2	1.4	
Crops					
Alfalfa		Acres			975
Small grain		Acres			375
Potatoes		Acres			150
Crop Root Zone Depths					
Alfalfa		Ft.	5	5	
Small grain		Ft.	4	4	
Potatoes		Ft.	3	3	
Net Irrigation Application (I)					
Alfalfa		In.	5.5	3.5	
Small grain		In.	4.4	2.8	
Potatoes		In.	2.6	1.7	
Consumptive Use Rate for Peak Month (u_m)					
Alfalfa		In./mo.	8.5	8.5	
Small grain (1.89" in 17 days)		In./mo.	3.4	3.4	
Potatoes		In./mo.	7.4	7.4	
Peak Period Consumptive Use Rates (u_p) (from table 5)					
Alfalfa		In./day	.30	.31	
Small grain		In./day	.13	.13	
Potatoes		In./day	.28	.29	
Weighted for crop distribution					
Alfalfa	65%	In./day	.195	.202	
Small grain	25%	In./day	.033	.033	
Potatoes	10%	In./day	.028	.029	
All crops	100%	In./day	.256	.264	
Weighted for soils distribution		In./day	.159	.100	.259

use. This excess is lost either to surface runoff or to percolation below the root zone depth. When such storms occur soon after an application of irrigation water has been made, almost all of the rainfall may be lost. Thus in areas of high total growing season rainfall, the effectiveness of rainfall is low by comparison.

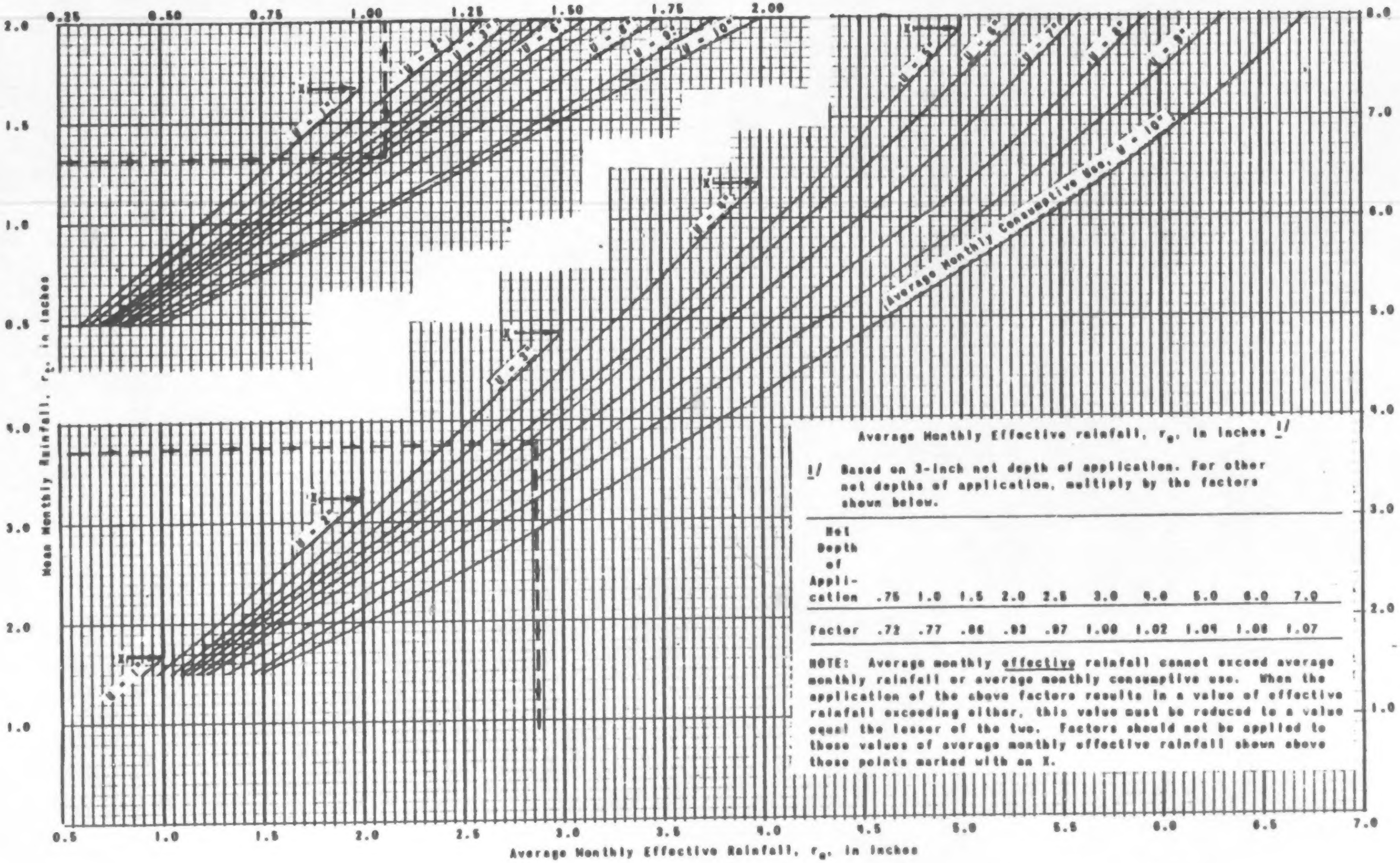
For example at Albuquerque, New Mexico, where the average total growing season rainfall is only 8.0 inches, the average rainfall effectiveness is 92 percent. At Baton Rouge, Louisiana, the average total growing season rainfall is 39.4 inches but the average rainfall effectiveness is only 64 percent.

Consumptive-use rate.--Where the consumptive-use rate of a crop is high, available moisture in the soil profile is depleted rapidly, thus providing storage capacity at a relatively rapid rate for receiving rainfall. Should a substantial storm occur, the amount of water required to bring the moisture in the profile back to the field capacity level would be relatively large and the losses due to runoff and/or deep percolation would be relatively small. Conversely, where the consumptive-use rate is low, storage capacity for rainfall is provided at a slower rate. When a storm occurs, there is less capacity in the profile available to receive water and thus the losses will be relatively large. Said briefly, the higher the rate of consumptive use, the greater will be the rainfall effectiveness. Conversely, the lower the rate of consumptive use, the lower will be the effectiveness of rainfall.

Net irrigation application.--As previously stated, the net irrigation application is dependent upon the capacity of the soil profile at root zone depth to store readily available moisture for plant use. When this capacity is low and a storm of considerable magnitude occurs, only a small percentage of the precipitation may be needed to fill the soil profile to field capacity and the resulting rainfall effectiveness will be low. Conversely, if the capacity is high, all or most of the rainfall resulting from such a storm might be stored in the profile before the field capacity level is reached. In this case, the effectiveness of rainfall would be relatively high.

Monthly Effective Rainfall.

Curves and tables have been developed to show the relationship between effective rainfall and the three variable factors discussed previously (see figure 3 and table 6). Either the curves or the table may be used with the same result and both are presented in order to give the user a choice. The curves and the table show the relationship between average monthly effective rainfall (r_e), mean monthly rainfall (r_t), and average monthly consumptive use (u). The values of (r_e) are based on a 3-inch net irrigation application. Factors for converting to other net depths of application are presented. For example, a crop of corn grown on a sandy soil has a net depth of application of 2.0 inches. Average consumptive use for the month of July is 8.79 inches and mean July rainfall is 5.85 inches. From figure 3 or table 6, the average effective rainfall for July is 4.91 x 0.93 = 4.57 inches.



Average Monthly Effective rainfall, r_e, in inches 1/

1/ Based on 3-inch net depth of application. For other net depths of application, multiply by the factors shown below.

Net Depth of Application	.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0
Factor	.72	.77	.86	.93	.97	1.00	1.02	1.04	1.06	1.07

NOTE: Average monthly effective rainfall cannot exceed average monthly rainfall or average monthly consumptive use. When the application of the above factors results in a value of effective rainfall exceeding either, this value must be reduced to a value equal the lesser of the two. Factors should not be applied to those values of average monthly effective rainfall shown above those points marked with an X.

Figure 3 - Average monthly effective rainfall as related to mean monthly rainfall and average monthly consumptive use

Table 6.--Average monthly effective rainfall 1/ as related to mean monthly rainfall and average monthly consumptive-use

Monthly Mean Rainfall r_t Inches	Average Monthly Consumptive-Use, u, in Inches									
	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
	Average Monthly Effective Rainfall, r_e, in Inches									
0.5	.30	.32	.35	.36	.37	.40	.42	.45	.47	.50
1.0	.60	.65	.70	.72	.74	.79	.82	.88	.98	1.00
1.5	.90	.98	1.05	1.10	1.13	1.17	1.22	1.32	1.45	1.50
2.0	$\frac{1.00}{1.67}$	1.29	1.38	1.43	1.47	1.56	1.62	1.75	1.88	2.00
2.5		1.59	1.70	1.78	1.84	1.94	2.02	2.15	2.30	2.50
3.0		1.85	1.99	2.11	2.20	2.30	2.41	2.55	2.70	2.95
3.5		$\frac{2.00}{3.23}$	2.27	2.41	2.55	2.64	2.79	2.95	3.11	3.38
4.0			2.55	2.71	2.88	2.97	3.15	3.32	3.51	3.80
4.5			2.82	3.00	3.21	3.30	3.49	3.71	3.92	4.22
5.0			$\frac{3.00}{4.87}$	3.26	3.51	3.62	3.83	4.09	4.32	4.63
5.5				3.55	3.81	3.95	4.17	4.45	4.71	5.04
6.0				3.81	4.09	4.24	4.50	4.80	5.08	5.44
6.5				$\frac{4.00}{6.37}$	4.35	4.52	4.80	5.12	5.42	5.81
7.0					4.60	4.80	5.10	5.41	5.72	6.15
7.5					4.84	5.06	5.36	5.68	6.03	6.45
8.0	1.00	2.00	3.00	4.00	$\frac{5.00}{7.89}$	5.31	5.60	5.93	6.32	6.74

1/ Based on 3-inch net depth of application. For other net depths of application, multiply by the factors shown below.

Net Depth of Application	.75	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0
Factor	.72	.77	.86	.93	.97	1.00	1.02	1.04	1.06	1.07

Note: Average monthly effective rainfall cannot exceed average monthly rainfall or average monthly consumptive use. When the application of the above factors results in a value of effective rainfall exceeding either, this value must be reduced to a value equal the lesser of the two. Factors should not be applied to the values of average monthly effective rainfall shown below those encircled. Where mean monthly rainfall (r_t) is less than 0.5 inch it may be assumed to be 100 percent effective.

Seasonal Effective Rainfall.

Average growing season effective rainfall is determined by adding the values of average effective rainfall for the several months and fractions thereof that cover the total growing season of the crop in question. (See Sample Calculations No. 4 and No. 5.)

Caution in the Use of the Curves and the Table.

Figure 3 and table 6 are the result of a comprehensive analysis of 50 years of precipitation records at each of 22 Weather Bureau stations so selected that all climatic conditions throughout the 48 continental states were represented. These studies were made by using the daily soil moisture balance procedure whereby a soil moisture balance is computed for each day by subtracting consumptive use and adding effective rainfall and/or irrigation to the previous day's balance. This procedure necessarily fails to consider two factors which, in some instances, may have a bearing on the effectiveness of rainfall. These factors, soil intake rates and rainfall intensities, are not considered for two reasons: (1) sufficient data are not available; and (2) the complexity involved in their consideration would make such a study impractical. In some areas where soil intake rates are low and rainfall intensities are consistently high, large percentages of rainfall may be lost to surface runoff without the moisture level in the soil profile being raised appreciably. In such areas the values obtained from figure 3 and table 6 may need to be modified.

Frequency Distribution of Effective Rainfall.

It can safely be assumed that, for any given crop at a particular location, monthly and seasonal consumptive use will vary only slightly from year to year provided the crop is planted at about the same time each year. On the other hand, monthly and seasonal effective rainfall can be expected to vary widely from year to year. Since by definition the net irrigation requirement is that portion of total consumptive use not supplied by effective rainfall or other natural sources, it will also vary widely from year to year as effective rainfall varies.

In view of this wide variation in net irrigation requirements from year to year, it is obvious that the development of a dependable water supply cannot be based on average requirements, since this would provide an adequate supply approximately half the time. It is common practice, therefore, to estimate effective rainfall and irrigation water requirements on a probability basis, the percent chance of occurrence used being an economic consideration. For example, it might be economical to provide a water supply that is adequate in nine out of ten years for a high-value vegetable crop or tobacco. For a low-value hay crop or pasture, it may not be economical to provide an adequate supply in more than six out of ten years.

The procedure for determining the frequency distribution of effective rainfall is based on the assumption that, for any fixed period of time or growing season at a given location, other factors being equal, effective rainfall will vary from year to year in direct proportion to the variance in total rainfall. Thus the frequency distribution of total rainfall may be used as a measure of the frequency distribution of effective rainfall. The procedure is as follows:

For the growing season of any given crop at a particular location, Weather Bureau records are used to determine the total rainfall that occurred during the growing season for each year over a period of 25 years or longer. These growing-season rainfall totals are then ranked in order of magnitude and plotted on log-normal probability paper as illustrated by figure 4. A straight line that most nearly fits all of the plotted points is drawn to establish the frequency distribution of growing-season total rainfall. Instructions for plotting the points and drawing the frequency distribution line are contained in the SCS National Engineering Handbook, Section 4, Supplement A, Part 3.18.

The desired percent chance of the developed water supply being equaled or exceeded by the gross irrigation water requirements of the crop is then selected. In the case of corn grown near Raleigh, North Carolina, as illustrated by Sample Calculation No. 4, this selected chance is 20 percent. Thus the developed water supply would be adequate in 8 years out of 10 or 80 percent of the time. The ratio of 80 percent chance growing-season rainfall to average growing-season rainfall is then determined. It will be noted in figure 4 that the 80 percent chance growing-season rainfall is 14.0 inches. From Weather Bureau records, it is determined that the average rainfall for the growing season for corn is 17.87 inches. Thus the aforementioned ratio is 14.0/17.87 or .783. This ratio, when applied to the monthly and seasonal average rainfall values, as shown in column 3 of Sample Calculation No. 4, determines the 80 percent chance monthly and seasonal rainfall values shown in column 9 of the same calculation.

The monthly effective rainfall that can be expected for any frequency of occurrence can be estimated by the use of figure 3 or table 6 when monthly consumptive use and monthly total rainfall for that frequency of occurrence are known. Again using Sample Calculation No. 4 as an example, the monthly consumptive-use values shown in column 2 and the 80 percent chance monthly total rainfall shown in column 9 are used with figure 3 or table 6 to obtain the 80 percent chance monthly effective rainfall shown in column 10.

An Alternate Procedure.

In cases where the degree of accuracy desired does not warrant the time required to plot a growing season rainfall frequency distribution curve for each crop under consideration, an alternate procedure may be used. This procedure involves the application of an average ratio to the average growing season effective rainfall to obtain the growing season effective rainfall for any given percent chance of occurrence. These average ratios vary with the desired percent chance of occurrence and with average annual rainfall values as shown in table 7.

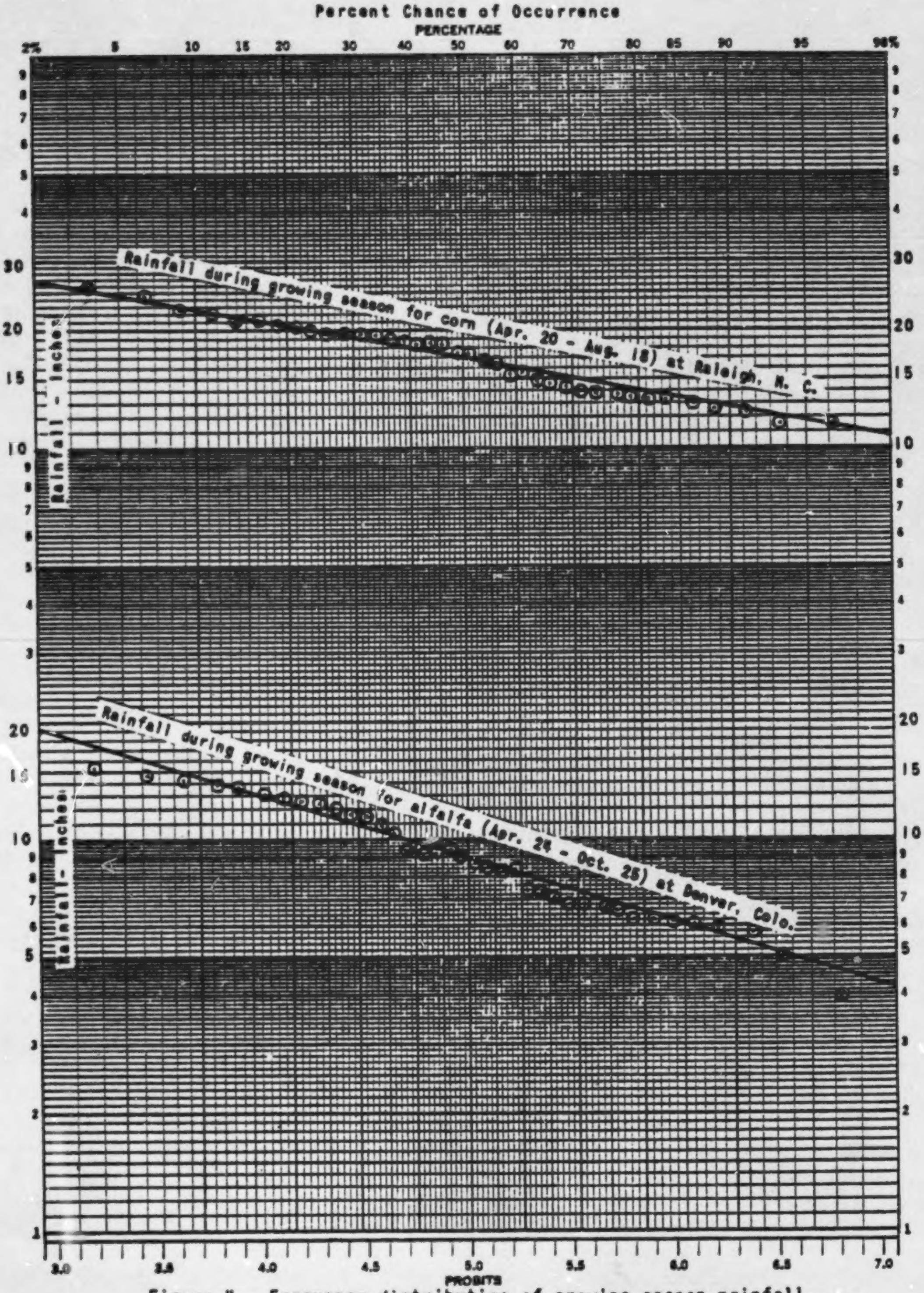


Figure 4 - Frequency distribution of growing season rainfall.

Again using corn at Raleigh, North Carolina, as an example, it is desired to find the growing season effective rainfall that will have an 80 percent chance of occurrence. Average total annual rainfall at Raleigh is 45.92 inches and it has been determined that the average growing season effective rainfall for corn is 12.72 inches (see Sample Calculation No. 4). From table 7 it will be noted that the average ratio applicable to effective rainfall is .842. Thus the growing season effective rainfall that may be expected to occur or be exceeded in eight out of ten years would be .842 x 12.72 or 10.71 inches.

The frequency distribution of effective rainfall for months or other short-time periods may be determined by applying these same ratios shown in table 7.

Irrigation Water Requirements

Consumptive-use data are used in estimating the irrigation water requirements of existing or proposed projects and for crop production on individual farms. The consumptive irrigation water requirement is dependent not only on the total consumptive need, but also on the amount of moisture contributed from such natural sources as effective growing-season rainfall, carryover soil moisture from winter rains and any contribution from ground water. Effective rainfall has been discussed in preceding paragraphs. The other two natural sources are discussed below.

Carryover Soil Moisture.

The contribution of carryover soil moisture resulting from winter rains to the seasonal water requirements is difficult to estimate. In some areas, winter precipitation is sufficient to bring the soil moisture in the root zone depth of the profile up to field capacity. This is particularly true in the humid area states where it is the custom to deduct this readily available moisture (equivalent to the net irrigation application) from seasonal consumptive use when estimating seasonal consumptive irrigation requirements. Where late-season water supplies are short, (usually arid areas) the soil moisture is often well below field capacity and possibly down to the wilting point in the fall.

For crops with a 6-foot root zone, the amount of usable water that could be stored might range from 1 to 2 inches of water per foot depth of soil, or 6 to 12 inches in the 6-foot root zone. This is a major part of the annual requirement of some crops and can be supplied by winter precipitation in some areas in wet years. However, in areas where irrigation water is plentiful, it is not unusual to find the soil moisture content at the end of the season nearly as high as at the beginning. Thus, there is no storage capacity left in the root zone and the contribution from winter precipitation is negligible. Nevertheless, the quantity of moisture carried over in the soil from winter precipitation tends to offset any deficiency in the estimated irrigation water requirements.

Table 7.--Average ratios applicable to effective rainfall

Average Annual Rainfall (Inches)	Percent Chance of Occurrence				
	50	60	70	80	90
3	0.80	0.68	0.56	0.45	0.33
4	.84	.72	.61	.50	.38
5	.87	.76	.65	.54	.42
6	.88	.78	.68	.57	.45
7	.89	.79	.69	.60	.48
8	.90	.81	.71	.62	.51
9	.91	.82	.73	.63	.53
10	.92	.83	.75	.65	.55
12	.93	.85	.78	.69	.58
14	.94	.86	.79	.71	.61
16	.95	.88	.81	.73	.63
18	.95	.89	.82	.74	.65
20	.96	.90	.83	.75	.67
22	.96	.90	.84	.77	.69
24	.97	.91	.84	.78	.70
26	.97	.92	.85	.79	.71
28	.97	.92	.86	.80	.72
30	.97	.93	.87	.81	.73
35	.98	.93	.88	.82	.75
40	.98	.94	.89	.83	.77
45	.98	.94	.90	.84	.78
50	.98	.95	.91	.85	.79
55	.99	.95	.91	.86	.80
60	.99	.95	.91	.87	.81
70	.99	.95	.92	.88	.83
80	.99	.95	.92	.89	.85
90	.99	.96	.93	.90	.86

Example of Use.
It is desired to find the growing season effective rainfall that will occur or be exceeded in 8 out of 10 years at a location where the average total annual rainfall is 30 inches and for a growing season where the average effective rainfall is 12 inches. From the table, the applicable ratio is found to be 0.81. Thus the 80% chance growing season effective rainfall is 0.81 x 12 = 9.72 inches.

Ground Water Contribution.
In areas of high natural ground water, the irrigation requirement may be materially less than if ground water were not available. However, if the high ground water is the result of excess irrigation, the overall demand on the irrigation supply by the crops is not decreased. In such a case, part of the irrigation is obtained by underground methods. As an example, studies in San Fernando Valley in Southern California indicated a consumptive use of water by alfalfa of 37 inches during the irrigation season. In areas of high water table in this valley, only 24 inches of surface irrigation water was required to produce a good yield of alfalfa. The additional 13 inches came from underground water supplies and a small amount of summer precipitation. As with carryover soil moisture, the contribution of ground water to seasonal water requirements is difficult to estimate.

Net Field Irrigation Requirements.
Net field irrigation water requirements for any period of time are estimated by subtracting from potential consumptive and other uses that moisture that is supplied by one or more of the three natural sources previously mentioned.

As previously stated, the effective rainfall studies were made by using the daily soil moisture balance method in which a balance is computed for each day by subtracting consumptive use and adding effective rainfall and/or irrigation to the previous day's balance. In using this method, daily balances are calculated from an assumed soil moisture level at the beginning of the growing season. In these studies, it was assumed that this level was field capacity. In using figure 3 or table 6 to determine net irrigation water requirements, an estimate of anticipated soil moisture conditions at the start of the growing season must be made. The depth of water, if any, required to bring the moisture level in the soil profile up to field capacity must be added to the irrigation water requirements obtained from the use of figure 3 or table 6.

Sample Calculation No. 4 illustrates the procedure for estimating both average net irrigation requirements and those net requirements than can be expected to be equaled or exceeded in two out of ten years using a crop of corn grown in an area near Raleigh, North Carolina. In this case it has been assumed that winter precipitation will bring the soil moisture level up to field capacity and provide 2.0 inches of carryover soil moisture. This 2.0 inches represents the amount of moisture between the 50 percent level and field capacity and is also equivalent to the net depth of application. It has been assumed that each farmer in a project starts irrigating when the soil moisture reaches the 50 percent level and applies enough water to bring the moisture level up to field capacity. Then, at any given time the average soil moisture level over the entire project area will approximate 75 percent. The amount of moisture between the 50 and 75 percent levels (equivalent to one-half the net depth of application or 1.00 inch in this case) has been carried over from month to month and finally consumed at the end of the growing season as shown in the calculation. This leaves the moisture in the soil profile at approximately the 50 percent level at that time. The procedure for estimating gross irrigation requirements is also illustrated.

Sample Calculation No. 5 illustrates the same procedures using a crop of alfalfa grown in an area near Denver, Colorado. In this instance it has been assumed that winter precipitation will provide 2.0 inches of carryover soil moisture and that a net pre-irrigation of 2.2 inches will be needed to bring the soil moisture level up to field capacity. The sum of the carryover moisture and the pre-irrigation, or 4.2 inches, is the net depth of application. As in the previous calculation, one-half the net depth of application or 2.1 inches has been carried through the growing season and used at its end.

Field Application Efficiencies.

Due to unavoidable losses, no field application of irrigation water can ever be 100 percent efficient. Thus more water than is needed to satisfy net irrigation requirements must be applied. A reasonably accurate estimate of field application efficiencies must therefore be made in order to estimate gross field irrigation requirements.

Application losses include evaporation, deep percolation, and surface runoff. The extent of such losses will depend on a number of different factors. The principal ones are discussed in succeeding paragraphs.

Intake characteristics of soils.--In general, considerable loss of water due to deep percolation may be expected when coarse-textured soils with high intake rates are irrigated by surface methods. On the other hand, when fine-textured soils with very low intake rates are irrigated by these methods, considerable losses will occur in the form of excess surface runoff. In either case, field application efficiencies are adversely affected.

Variations in soil intake rates are also a factor in lowering application efficiencies. The intake rate of most soils on which a rotation of crops is grown will vary widely both throughout the growing season and from year to year within the rotation period. Unless considerable flexibility is designed into the irrigation system and the irrigator has the skill required to adjust stream sizes to these changing intake rates, field application efficiences will be materially lowered.

Topography.--It is more difficult to control the flow of water on sloping land than it is on level or near-level land. When relatively steep slopes are irrigated by either of the furrow, corrugation, border or contour ditch methods, excessive surface runoff can be expected where enough water is applied to meet crop requirements. Highest application efficiencies are attained where the land is nearly level and all irregularities are removed by land leveling.

Where fields are subirrigated, the difficulty in maintaining a water table approximately parallel to the land surface increased rapidly as

SAMPLE CALCULATION NO. 4

Estimate of monthly and seasonal irrigation requirements
by
Corn at Raleigh, North Carolina

(1) Month	(2) Average Monthly Cons. Use, u. Inches	(3) Mean Monthly Rainfall, r_t Inches	(4) Average Monthly Effective Rainfall r_e, Inches	(5) Average Carryover Soil Moisture Inches	(6) Average Net Irrig. Requirement i_n, Inches	(7) Estimated Field Appl. Efficiency Percent	(8) Average Gross Irrig. Requirement i_g, Inches	(9) 80% Chance Monthly Rainfall, r_t, Inches	(10) 80% Chance Monthly Effective Rainfall r_e, Inches	(11) 80% Chance Carry-over Soil Moisture, Inches	(12) 20% Chance Net Irrig. Require. i_n Inches	(13) 20% Chance Gross Irrig. Require. i_g, Inches
				2.00						2.00		
Apr. 20	0.70	1.20	0.61		None	70	None	0.94	0.54		None	None
				1.91						1.84		
May	3.52	3.62	2.23		0.38	70	0.54	2.83	1.80		0.88	1.25
				1.00						1.00		
June	7.84	4.05	3.08		4.76	70	6.80	3.17	2.47		5.37	7.67
				1.00						1.00		
July	8.79	5.85	4.57		4.22	70	6.03	4.58	3.64		5.15	7.36
				1.00						1.00		
Aug. 18	4.10	3.15	2.23		0.87		1.24	2.47	1.80		1.30	1.86
				0.00						0.00		
Season Totals	24.95	17.87	12.72	2.00	10.23	70	14.61	13.99	10.25	2.00	12.70	18.14

Note: Explanation of column headings appears on the reverse side of this page.

EXPLANATION OF COLUMN HEADINGS - SAMPLE CALCULATION NO. 4

(2) Consumptive-use values shown in this column are taken from Sample Calculation No. 1, column 11.

(3) Mean monthly rainfall values are taken from Weather records.

(4) Values of monthly effective rainfall are obtained by using the values shown in columns 2 and 3 together with table 6 (using a 2.0-inch net depth of application for corn at Raleigh, N.C.). Values in table 6 are for whole months only. To obtain a value for a part of a month, the values shown in columns 2 and 3 must first be converted proportionately to whole month values and table 6 then used to obtain effective rainfall for the entire month. This latter value is then converted back proportionately to obtain the effective rainfall for the actual number of days involved.

(5) Carryover soil moisture must be estimated. In this case it is assumed the winter rains will bring the soil profile up to field capacity, thus the amount of carryover soil moisture will be equal to the net depth of application or 2.0 inches. On an average, one-half of this carryover soil moisture will be consumptively used before irrigation is started and one-half will be carried over for use at the end of the growing season.

(6) The average net irrigation requirement for any month is obtained by subtracting the sum of the values shown in columns 4 and 5 from the value shown in column 2.

(7) Values of obtainable field application efficiencies are taken from the conservation irrigation guide covering the area concerned.

(8) Gross irrigation requirements are obtained by dividing the values shown in column 6 by those shown in column 7.

(9) Values of monthly rainfall for any frequency of occurrence are obtained by first plotting a rainfall frequency distribution curve (see curve for Raleigh, N. C., figure 4) and then obtaining from the curve the value of the growing season rainfall for the desired frequency of occurrence, in this case 8 out of 10 years. This latter value divided by the average growing season rainfall will give a percentage factor which, when applied to the values shown in column 3, will give the values of monthly rainfall shown in column 9 on a frequency basis.

(10) The values of monthly effective rainfall shown in this column are obtained by using the values shown in columns 2 and 9 together with table 6. See explanation of column 4.

(11) See explanation of column 5.

(12) The net irrigation requirements for any month are obtained by subtracting the sum of the values shown in columns 10 and 11 from the value shown in column 2.

(13) Gross irrigation requirements are obtained by dividing the values shown in column 12 by those shown in column 7.

SAMPLE CALCULATION NO. 5
Estimate of monthly and seasonal irrigation requirements
Alfalfa at Denver, Colorado

(1) Month	(2) Average Monthly Cons. Use, u. Inches	(3) Mean Monthly Rainfall, rt Inches	(4) Average Monthly Effective Rainfall re, Inches	(5) Average Carryover Soil Moisture Inches	(6) Average Net Irrig. Requirement in, Inches	(7) Estimated Field Appl. Efficiency Percent	(8) Average Gross Irrig. Requirement ig, Inches	(9) 80% Chance Monthly Rainfall, rt Inches	(10) 80% Chance Monthly Effective Rainfall re, Inches	(11) 80% Chance Carryover Soil Moisture Inches	(12) 20% Chance Net Irrig. Require. in, Inches	(13) 20% Chance Gross Irrig. Require. ig, Inches
				2.00						2.00		
Pre-Irrigation					2.20	75	2.93				2.20	2.93
				4.20						4.20		
Apr. 24	0.57	0.49	0.33		None	75	None	0.34	0.23		None	None
				3.96						3.86		
May	3.99	2.70	1.98		0.15	75	0.20	1.87	1.47		0.76	1.01
				2.10						2.10		
June	6.36	1.44	1.15		5.21	75	6.95	1.00	0.79		5.57	7.43
				2.10						2.10		
July	7.80	1.53	1.32		6.48	75	8.64	1.06	0.91		6.89	9.19
				2.10						2.10		
Aug.	6.66	1.28	1.03		5.63	75	7.50	0.89	0.71		5.95	7.93
				2.10						2.10		
Sept.	4.00	1.13	0.83		2.45	75	3.27	0.78	0.54		2.92	3.89
				1.38						1.56		
Oct. 25	1.89	0.81	0.51		--			0.56	0.33		--	
				0.00						0.00		
Season Totals	31.27	9.38	7.15	2.00	22.12	75	29.49	6.50	4.98	2.00	24.29	32.38

Note: Explanation of column headings appears on the reverse side of this page.

EXPLANATION OF COLUMN HEADINGS - SAMPLE CALCULATION NO. 5

(2) Consumptive-use values shown in this column are taken from Sample Calculation No. 2, Column 10.

(3) Mean monthly rainfall values are taken from Weather Bureau records.

(4) Values of monthly effective rainfall are obtained by using the values shown in columns 2 and 3 together with table 6 (using a 4.2-inch net depth of application for alfalfa at Denver, Colorado). Values in table 6 are for whole months only. To obtain a value for a part of a month, the values shown in columns 2 and 3 must first be converted proportionately to whole month values and table 6 then used to obtain effective rainfall for the entire month. This latter value is then converted back proportionately to obtain the effective rainfall for the actual number of days involved.

(5) In this case it is assumed that there is a 2.0-inch soil-moisture carryover and that a 2.2-inch net irrigation will be required to bring the moisture level in the profile up to field capacity. The sum of these, or 4.2 inches, will equal the net depth of application and is treated as carryover moisture in the calculations. On the average, one-half of this carryover soil moisture will be consumptively used before irrigation is started and one-half will be carried over for use at the end of the growing season.

(6) The average net irrigation requirement for any month is obtained by subtracting the sum of the values shown in columns 4 and 5 from the value shown in column 2.

(7) Values of obtainable field application efficiencies are taken from the conservation irrigation guide covering the area concerned.

(8) Gross irrigation requirements are obtained by dividing the values shown in column 6 by those shown in column 7.

(9) Values of monthly rainfall for any frequency of occurrence are obtained by first plotting a rainfall frequency distribution curve (see curve for Denver, Colorado, figure 4) and then obtaining from the curve the value of the growing season rainfall for the desired frequency of occurrence, in this case 8 out of 10 years. This latter value divided by the average growing season rainfall will give a percentage factor which, when applied to the values shown in column 3, will give the values of monthly rainfall shown in column 9 on a frequency basis.

(10) The values of monthly effective rainfall shown in this column are obtained by using the values shown in columns 2 and 9 together with table 6. See explanation of column 4.

(11) See explanation of column 5.

(12) The net irrigation requirements for any month are obtained by subtracting the sum of the values shown in columns 10 and 11 from the value shown in column 2.

(13) Gross irrigation requirements are obtained by dividing the values shown in column 12 by those shown in column 7.

slopes increase above one-half percent.

Climate.--In arid and semi-arid areas where air temperatures and wind velocities are high, appreciable losses may be expected from the resulting evaporation. These tend to lower application efficiencies of all methods of irrigation except subirrigation. Sprinkler irrigation is particularly affected. High wind velocities so distort the distribution pattern that high application efficiencies are not attainable.

Net depth of irrigation.--The amount of water applied at one irrigation and stored in the soil profile for plant use will affect the application efficiency with some methods of irrigation. In the case of sprinklers, for example, the water retained on the plant foliage and that evaporated from the ground surface while sprinkling is in process will be approximately the same regardless of the depth of application. Thus these losses will be greater percentage-wise for light applications. In the case of graded furrows or corrugations, the amount of water lost to deep percolation will be approximately equal for both light and heavy applications. Generally speaking, then, with these methods, lighter applications will be made at lower efficiencies than will heavier applications.

Irrigation methods.--Relatively high application efficiencies can be attained by most methods of irrigation where the soils, topographic, and climatic conditions are favorable. However, for any given set of conditions, usually a higher application efficiency can be attained with one method than can be attained with another. For example, a close-growing crop on a near-level field where wind velocities exceed 15 miles per hour could be irrigated by the border method with a high application efficiency. Under the same conditions a sprinkler system would have a much lower application efficiency. If the same crop were to be irrigated on a sloping field with relatively calm wind conditions, the sprinkler system would prove to be more efficient. Thus in order to attain a high application efficiency, it is important that the most adaptable method of irrigation be selected.

Adequacy of system design and installation.--In order to attain a high application efficiency, any irrigation system, regardless of method, must be adequately designed and properly installed. The system must include all structures and other devices necessary for controlling the irrigation stream. The extent to which this is accomplished will, in large measure, determine the application efficiency that can be reached.

Skill of the irrigator.--A most important factor influencing field application efficiency is the skill of the irrigator and his interest in using that skill to practice good water management. All of the influential factors mentioned above may be favorable but, unless the irrigator operates the system according to plan, applying water as needed by the crop and at a rate commensurate with the soil intake rate, a high application efficiency will not be attained.

Tailwater recovery systems.--In some instances where the graded furrow and border methods of irrigation are used, relatively large percentages of surface runoff cannot be avoided due to low soil intake rates. In such cases, field application efficiencies are low. Approximately 50 to 65 percent of these losses can be recovered, however, for re-use where tailwater recovery systems are installed. These are systems whereby the runoff from graded furrow and border systems is collected and either pumped back for re-use on the same field or allowed to flow by gravity onto other fields of lower elevation. The use of such a system will materially increase the overall application efficiency on the farm.

Estimating field application efficiencies.--After all of the aforementioned influential factors have been given due consideration, field application efficiencies may best be estimated by referring to that chapter of Section 15 of the SCS National Engineering Handbook covering the specific method of irrigation contemplated or by referring to applicable local irrigation guides.

Gross field irrigation requirements.--Sample Calculations Nos. 4 and 5 also illustrate the procedure involved in estimating gross field irrigation requirements. To determine average gross requirements, the average net requirements shown in column 6 are divided by the estimated field application efficiency shown in column 7. To determine the gross field requirements that can be expected to be equaled or exceeded 20 percent of the time, the 20 percent net requirements shown in column 12 are divided by the same estimated field application efficiency shown in column 7.

Requirements for Related Purposes

In irrigated agriculture, there are occasions where water is needed for purposes other than irrigation but where irrigation systems must be used to apply the water. Where water is used for these additional purposes, their annual requirements must be estimated and added to those for irrigation. Water requirements for the more important of these related purposes are discussed in succeeding paragraphs.

Leaching Requirements

The removal of harmful soluble salts from the crop root zone is essential in irrigated soils if sustained high crop production is to be maintained. Without removal, salts accumulate in direct proportion to the salt content of the irrigation water and the depth of water applied. The concentration of the salts in the soil solution results principally from the extraction of moisture from the soil by the processes of evaporation and transpiration. Such salt concentrations can only be removed by passing enough water through the soil profile to dissolve the harmful soluble salts and transport them, by the downward movement of the water, out of or beyond the crop root zone. This process is known as leaching.

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CLIMATE AND WASTEWATER STORAGE

Objectives

Upon completion of this module, the participant should be able to indicate:

1. The most important variable in the determination of the amount of storage.
2. The factors that define an unfavorable day for application for:
   a. The EPA-1 computer program for estimating storage.
   b. The EPA-2 computer program for estimating storage.
   c. The EPA-3 computer program for estimating storage.
3. The derivation of the freeze index and the use of the freeze index for estimating wastewater storage requirements.
4. Indicate the variables that are considered in a water balance in an arid area.
5. Why runoff from a site must be avoided.
6. Indicate options for dealing with runoff.

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Script to Accompany the A-T
CLIMATE AND WASTEWATER STORAGE
Module 8
January, 1978

CLIMATE AND WASTEWATER STORAGE

(Slide 1) This module discusses the wastewater storage and runoff controls that are an essential part of all wastewater land treatment systems (Slide 2). Even though a system may receive about the same amount of waste every day, various hydrologic and climatic constraints (Slide 3) may prevent applying that amount daily to the land. When this is the case, facilities for storing the wastewater must be built into the system. Hydrologic and climatic considerations also play a major role in determining the type and amount of runoff control that is necessary at a particular site. In order to take full advantage of the renovating capacity of the soil and in order to protect adjacent land and surface waters, all runoff from a land treatment site must be avoided. In most cases, any runoff that does occur is collected and cycled to the storage area for later treatment. Thus, there must be storage for the potential runoff from an extreme storm on the site. The objectives for this lesson are located in an envelope that is in the lesson package. Stop the tape recorder and study the objectives (Slide 4). You may keep the objectives for reference during the lesson.

The amount of storage that is built into a land treatment system depends upon several factors, the most important probably being the type of system chosen for treating the waste. As shown in Slide 5, rapid infiltration systems may apply waste year round and, thus, the size of the storage area will be determined by the application schedule. The rapid infiltration system that has been in operation year round for over twenty-five years at Lake George, New York has a very limited storage for those times when the temperature falls to below 10°F.

Slide 6 shows the extensive storage areas for an (irrigation) system. There are several important reasons for storage in these slow rate systems as indicated in Slide 7. Storage protects the application equipment from damage due to freezing. When temperatures approach the freezing point the chemical and biological activity necessary for renovation of the wastewater essentially stops. The storage allows the operator to not apply at those times when the soil is saturated. This helps prevent runoff, erosion, and ponding. Storage also helps control the variations in flow that are typical of municipal sewer systems, especially those with combined sanitary and storm sewers. Finally, in arid areas where irrigation is essential for the growth of a crop, storage provides the opportunity to apply the water according to the crop needs.

The National Climatic Center, a department of the National Oceanic and Atmospheric Administration has designed computer programs that provide estimates of storage requirements using twenty to thirty years of daily climatological data (Slide 8). The three computer programs, EPA-1, EPA-2, and EPA-3 that have been developed are each especially suited to different areas of the country. These areas are shown in Slide 9. EPA-1 and EPA-3 are designed for use in regions where winter cold and snow are the predominant constraint to application, while EPA-2 is suitable for wet regions. Each program results in a summary of the unfavorable days for application of waste for every year for the weather reporting station closest to the planned site. A summary sheet from one of the programs is shown in Slide 10. These summaries are based on several variables the value of which can be changed to suit the specific conditions of the proposed site. Also, recurrence intervals and confidence intervals for different factors are indicated. The following portion of this lesson will describe the details and uses of each of the three EPA programs.

The EPA-1 program was designed for areas where the main constraint in the operation of a land treatment site is cold and snow. This program should only be used if the temperature falls below 32°F for two consecutive weeks or more during the winter. Those areas are indicated in Slide 11. The program defines each day as favorable or unfavorable for operation on the basis of three variables. While the threshold of these variables can be changed, the values indicated in Slide 12 were the ones that were initially chosen to run the program. An unfavorable day is one with the mean temperature of 32°F or below, or 1 inch or more of snow cover, or 1/2 inch of precipitation. The storage amount is estimated by adding one day's flow to the storage for each unfavorable day. Favorable days for application reduce the storage by the drawdown rate, which includes the current days flow plus the portion of the daily flow that can be applied. In this case the drawdown rate is 1.50 so a favorable day would reduce accumulated storage by .50 (Slide 13). An example of several days data is printed in Slide 14. Notice that the unfavorable days increased the accumulated storage while the favorable days decreased the storage by 0.50.

EPA-3 is similar to EPA-1 with some minor modifications. EPA-3 is suitable for all areas indicated in Slide 15. As can be seen from the summary sheet of this program, in Slide 16, the threshold for a favorable day is still based on the amount of snow, and precipitation, and temperature. The temperature thresholds, however, include a maximum and minimum. For there to be a favorable day, in this case, the maximum temperature must be over 40°F and the minimum must be over 25°F. This program also computes partly favorable days. A partly favorable day is one that is above the threshold for precipitation and snow but the temperature drops below the minimum for some portion of the day. The temperature must still rise above the maximum, in this case 40°F, for some portion of the day. As can be seen in Slide 17, on a favorable day, the storage is decreased by the drawdown rate, in this case 1.50 day's flow. It must be remembered that this only decreases the accumulated storage by 0.50 days flow since the one represents the flow for that particular day. An unfavorable day increases storage needs by the daily flow. A partly favorable day, indicated by the letter L in the UNF column, increases storage by the daily flow minus one half the drawdown rate. Notice the partly favorable day in the slide. The storage on that day is increased by 0.25, which is the daily flow of 1 minus one half the drawdown rate of 1.50. Notice on this daily sheet that there are several other variables indicated. Usually the first three columns indicate the date and year but they are not included in this Slide because of space limitations. The program usually examines only the winter season from November through March. The first three columns in this Slide indicate the maximum, minimum, and mean temperatures. Then snow depth on the ground and precipitation are indicated. The next two columns indicate degree days and the cumulative degree days. As Slide 18 indicates, for this purpose, the degree days are found by subtracting 32° from the mean temperature. As is shown in Slide 19, the mean temperature for November 1, 1956 was 67°F giving 35 degree days for that day. These are accumulated from the beginning of the season which gives the cumulative degree days, abbreviated CDD. After the cumulative degree days the favorable days to apply column is displayed followed by a column that indicates the duration of favorable days in succession. The printout that is indicated in Slide 19 shows nine favorable days before there was an unfavorable day, which is indicated in the next column followed by the duration of unfavorable days in the DUR UNF column. The last column on the page indicates the accumulated storage for the season. The storage is always considered to be zero at the beginning of a season. This is a necessary, but not always valid, assumption for a particular site. The cumulative degree days are also assumed to be zero at the beginning of each season.

Slide 20 shows the last month of a season. At the bottom of the page is a row that summarizes that particular season. The first four figures in the summary concern the freeze index. The freeze index indicates the severity of a winter as far as degree days are concerned. Slide 21 indicates how the freeze index is computed. Remember that mean temperatures above 32°F decrease the cumulative degree days. The cumulative degree days for a mild winter and for a severe winter are graphed in Slide 22. The freeze index for each is also indicated. The next figure indicated on the data sheet for EPA-3 is the duration of the freeze index (Slide 23). This is the number of days between the high and low cumulative degree days. In this case there were 77 days between the extremes of the cumulative degree days. Under the FA column in the summary row is the longest consecutive run of favorable and partly favorable days. In this case there was a string of 10 days, sometime in the season, when at least some wastewater could be applied. The next number on the data sheet indicates the longest duration of unfavorable days. Finally the maximum amount of storage for the period examined is indicated. In this case it is 89 days of flow.

Slide 24 shows the summary page for a whole EPA-3 program. The years of record are ranked by the freeze index. The mean and statistical summary is indicated below this. Notice that in the statistical summary estimated storage days are calculated up to a fifty year recurrence interval, indicated by the column "STOR5 to STOR50" at the lower right.

There are various ways that EPA-1 and EPA-3 can be used. EPA-3 has all of the capabilities of EPA-1 plus the statistical summaries and partially favorable days. We will discuss the uses of the programs, therefore, using EPA-3 as an example. For systems that are designed to operate during the winter on a favorable day, the storage maximums are useful for system design. Slide 25 is the statistical portion of the EPA-3 summary sheet for Nashville, Tennessee. Notice that it is expected that about 62 days of storage would occur once in fifty years. The thresholds have been modified in a few ways from the usual EPA-3 programs. They have been altered so that the maximum temperature must be greater than 45°F in order to have a favorable day. Also the drawdown has been set at 1.33 rather than the usual 1.5. That means that on a favorable day the system is assumed to apply the current daily flow plus one third of the daily flow from storage. This is even more conservative than the 1.5 drawdown rate. This system could conservatively plan on about 65 days storage to take care of storage due to winter cold, snow and/or rain.

Some systems close down entirely during the winter, especially those in the cold northerly areas (Slide 26). For these systems, the freeze index and duration of the freeze index might be a better key for storage requirements. This index, however, is reliable only in areas of the country where the temperature remains below freezing for two weeks or more during the winter. Remember, this index indicates the difference from the highest to the lowest cumulative degree days. Slide 27 indicates the summary of the freeze index for the Rochester, New York station. 1962-63 was the most severe winter as far as low temperature was concernd as is indicated by its high freeze index. For systems that close down for the winter, however, the duration of the freeze index is more important than the index itself. The duration, which is the column that is highlighted, indicates the approximate length of time that the system must close down because of freezing temperatures. The winter of 1955-56 with a duration of 124 days is the maximum for this station. This program only examines the season from November through March. It might be better if the period of examination were extended through April for areas such as this that have severe winters because the low point of cumulative degree days, as indicated by the end of the freeze index, falls very near the end of March. There would, however, be only occasional times after the end of March when the system could not operate because of cold.

Rapid infiltration systems, like the one in Slide 28, operate successfully year-round in most areas of the country. These systems can apply the waste under snow and ice as is done in Lake George, New York. For these systems a small amount of storage would be necessary when the temperature is very cold, perhaps below 10°F. Storage would be necessary mainly to protect the equipment. Rain and snow would not affect these high rate systems. An EPA-1 program was modified for these conditions as indicated in Slide 29. The program was run for the weather station nearest Lake George, New York. The values for storage ranged up to 21 days for the most unfavorable winter. Although the EPA programs were designed for irrigation systems, they can be modified to suit other types of land application systems.

As is indicated in Slides 30 and 31, almost all slow rate systems depend upon a crop of some type to help renovate the applied wastewater and sludge. This is especially true for the uptake and removal of nitrogen and to a lesser extent the removal of phosphorus. In cold weather biological activity greatly decreases, in fact, nitrification essentially ceases below 40°F (Slide 32). The time between the storage period estimated by using the National Climatic Center EPA-1 and EPA-3 programs and the growing season, as compiled by the United States Department of Agriculture may be several weeks to two months as shown in Slide 33. During this time, nutrient uptake by the cover crop will be negligible. This injects a considerable time lag between National Weather Service storage recommendations, at an average daily temperature of 32°F and the USDA growing season recommendations for irrigated agriculture at an average daily temperature of 45°F. If traditional land application procedures are used and if nutrient uptake by the cover crop is to be relied upon, the growing season limitations must be respected in the design procedure. The EPA-1 and EPA-3 programs can be modified by adjusting the maximum, minimum or mean temperature thesholds to coincide with the growing season recommendations. Another way of modifying the program, for cold areas, is to have the cumulative degree days figured at a base of 40° or 45°F. This would adjust the freeze index to coincide with the growing season and would result in an estimate of storage that reflects the non-growing season. These adjustments are indicated in Slide 34. Also, the USDA records growing season duration for all areas of the country. There are low rate land application systems that are being developed that would allow operation in and out of the growing season. This would operate as indicated in Slide 35. These generally depend upon the nitrogen being in the ammonium form and being absorbed by the cation exchange complex in the cold period. When the soil warms up the pulse of nitrate that is produced is collected through underdrains and either reapplied or even sold as high nitrate fertilizer. For more information on alternate systems, see Module 15, "Nitrogen Considerations" (Slide 36).

The type of crop planted and its stage of development affects evapotranspiration and, as a consequence, the uptake of nutrients. Slide 37 shows the difference between a corn crop followed by wheat and a hay crop in evapotranspiration. If the transpiration portion of these figures could be separated it would be directly proportional to the amount of nutrients absorbed. Notice that the hay crop begins significant evapotranspiration much earlier in the spring. The daily evapotranspiration in the corn field is entirely due to evaporation before emergence at the end of May. That means that insignificant amounts of nutrients are absorbed by the crop before this time. If nutrient uptake is a main concern it would be wise to use a crop that begins growth very early in the spring and ends as late as possible in the fall.

There is a large area of the country, indicated in Slide 38, where the main constraint in the land application of wastes is not cold and snow but rain and saturated soil. For these sections of the country, the National Climatic Center has developed a program based on saturated soil conditions and the water holding capacity of the soil. This program is called EPA-2 and estimates storage using the several variables indicated in Slide 39. These include the available water capacity of the soil, the precipitation, the potential evapotranspiration based on the temperature and moisture of the soil, potential moisture loss from the underlying and surface soil, and runoff. The program defines a day as unfavorable whenever the amount of moisture in the soil is equal to or greater than the assigned available water capacity. An example of the daily output of this program is shown in Slide 40. Notice, first, that the available water capacity, designated by the user, is on the bottom row of the page. In this case, the available water capacity is six inches, either to bedrock or some other designated depth. The surface layer, or plow layer, labelled SS in the program is always assumed to have one inch of the available water capacity. This layer is saturated, therefore, when it contains an inch of water. The underlying layer, SU, contains the remaining available water capacity. Whenever the SS and SU columns are saturated an unfavorable day is registered. This happened on April 3rd and 4th in the example in Slide 40. There are variables in this program that are not included in this Slide that indicate several factors that involve moisture loss and gain in the soil. The details are not important for our purposes, because the data are summarized on the summary page of the program. Notice, however, that on April 5th the soil was one-hundredth of an inch below saturation. In this program, that day would be counted as a favorable day for application. In actuality, however, wastewater would not usually be applied to a soil that close to saturation. By adjusting the program, an unfavorable day can be indicated when the surface soil is above a designated percent of saturation. This is shown in Slide 41. The designation, EPA-2 = 10% indicates that an unfavorable day is to be indicated if the surface soil, column SS, is 90% or more of the available water capacity. The last seven days indicated in this Slide are affected by that threshold. The program user can change this threshold to suit his situation. Also notice in this Slide 41 that the available water capacity has been designated as ten inches, rather than the six inches in the last example.

The summary sheet for EPA-2 is shown in Slide 42. The UNF column indicates the longest unbroken run of unfavorable days for each year of record. The four columns on the far right of the page indicate the status of the soil moisture for the year. The "less than one" column indicates the number of days with less than one inch of available water in the soil. A high number in this or the adjacent column usually indicates a dry year. The recurrence intervals are indicated at the bottom of the summary. Notice that only once in fifty years would there be a run of 101 unfavorable days. This does not, however, indicate the amount of storage necessary. An examination of the year with 104 unfavorable days indicates why this is so. The 104 days began on November 14, 1928 and ran through March 15, 1929. Slide 43 indicates the beginning of that run. Notice that there are three unfavorable days, then a favorable day, then 18 unfavorable days, then another favorable day before the 104 days begin. This means that there were 21 days in storage with two favorable days in between. The designed storage would have to accommodate well over 104 days. An examination at the end of the 104 days would indicate a similar situation. It is essential, therefore, when using this program to examine the daily record for several of the worst years in the design of storage.

In arid areas there are several options for the design of storage. These are the areas indicated in Slide 44. Each of the options has advantages and disadvantages for particular situations. The simplest and the one involving the smallest storage requirement is to use the EPA-3 program. In most of the sites in arid areas the storage requirement would be less than two weeks flow, often less than a week's flow (Slide 45). In these areas, however, the growth of a crop requires irrigation water in variable quantities depending upon precipitation, stage of growth of the crop, and evapotranspiration. It may be necessary to irrigate with the wastewater in conjunction with crop needs. This usually means storing wastewater in the winter, when crop needs are lower and precipitation is higher, for use in the warmer months. Slide 46 indicates irrigation needs for specific crops in the Bakersfield, California area. In some months the crop needs, indicated by consumptive use, are met by precipitation and no irrigation is necessary. In other months the irrigation requirements are very high. The storage requirement, if the chief concern were to satisfy crop needs, would be extensive. A water balance for a particular area can be developed to determine storage needs while maintaining crop requirements and groundwater requirements. Slide 47 indicates the elements in a water balance of this type. The percolation in this case is the amount of water necessary to leach the soil of excess salts or to maintain groundwater quality in relation to a specific waste constituent. In areas where the soil does not become saturated to the groundwater level and where salts are not a problem this leaching factor may not be necessary. An example of a water balance worked out according to this formula is indicated in Slide 48. This is for a 1 mgd flow and an application area of 120 acres. The storage in this extreme case is 22.7" per acre which equals 73 days flow.

Closely related to the need for storage required by climatic events is the control of runoff that may result from climatic events. Land treatment sites should be protected from runoff events for several reasons as indicated in Slide 49. In addition, runoff control is usually required by the state agencies that control land application.

In design, additional storage facilities as well as land area may have to be provided for expected runoff events. This is true for overland flow systems, in which runoff is a part of the operation. Generally, the 25 year, twenty-four hour storm is used as the precipitation event from which all runoff must be contained. Slide 50 indicates the extent of this precipitation event for the eastern half of the United States. The situation is so variable in the western portion of the country that detailed maps of each state are the source of this information. Such a map, for Colorado, is shown in Slide 51. The National Weather Service can provide maps of this detail, and even by county, for every state, not only the western states. The expected runoff from this storm usually exceeds the expected daily runoff from a snow melt so the provisions for containing storm water will usually be adequate to handle a sudden thaw of snow. There are several options available for the handling of runoff as indicated in Slide 52. The option chosen depends in part on the type of system chosen for the land application. Some systems analyze the runoff, and if it meets discharge standards, release the runoff as a point source discharge. This is especially feasible in an overland flow system, since treated wastewater generally undergoes this type of analysis and discharge as normal operating procedure. If the system collects the runoff for re-application, there may be a significant storage amount involved. A six inch storm over a two hundred acre site produces about 33 million gallons of water. The maximum rainfall event usually occurs as a summer storm and in most cases there is enough storage because of other climatic considerations. Significant storage, however, must be provided in areas where the runoff from melting snow is a significant amount (Slide 53). The times when the snow is melting generally coincide with the times when there is a maximum amount of wastewater in storage due to previous unfavorable days for application (Slide 54). Information concerning the amount of water involved in snow melt can be obtained from the National Weather Service.

There are several options for containment and collection of excess water. Ridges, as shown in Slide 55, are generally the least expensive procedure for simple containment. Slides 56 and 57 show two of the methods of collection. These methods include grassed waterways, terraces, diversions, tail ditches, and on flat land, shallow surface drains. Any facilities that are used to collect runoff must have their banks protected against erosion by the establishment of a vegetative cover, usually a sod cover. These facilities also require regular maintenance as shown in Slide 58 to assure their being kept open and useful.

In summary, almost all land treatment sites include facilities for the storage of wastewater for those times when application is not possible or practical (Slide 59). The new computer programs are an aid to keeping the size of the storage area as small as possible with a reasonable safety factor, thus keeping costs to a minimum. Runoff control can also be planned from local climatological records. Adequate runoff control protects the site from erosion and prevents short circuiting of the waste treatment.